Perspectives in Land Reclamation and Restoration

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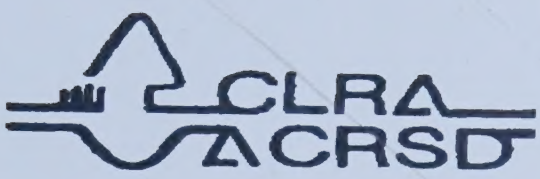

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Including the Canadian Land Reclamation Association's
24th Annual Meeting

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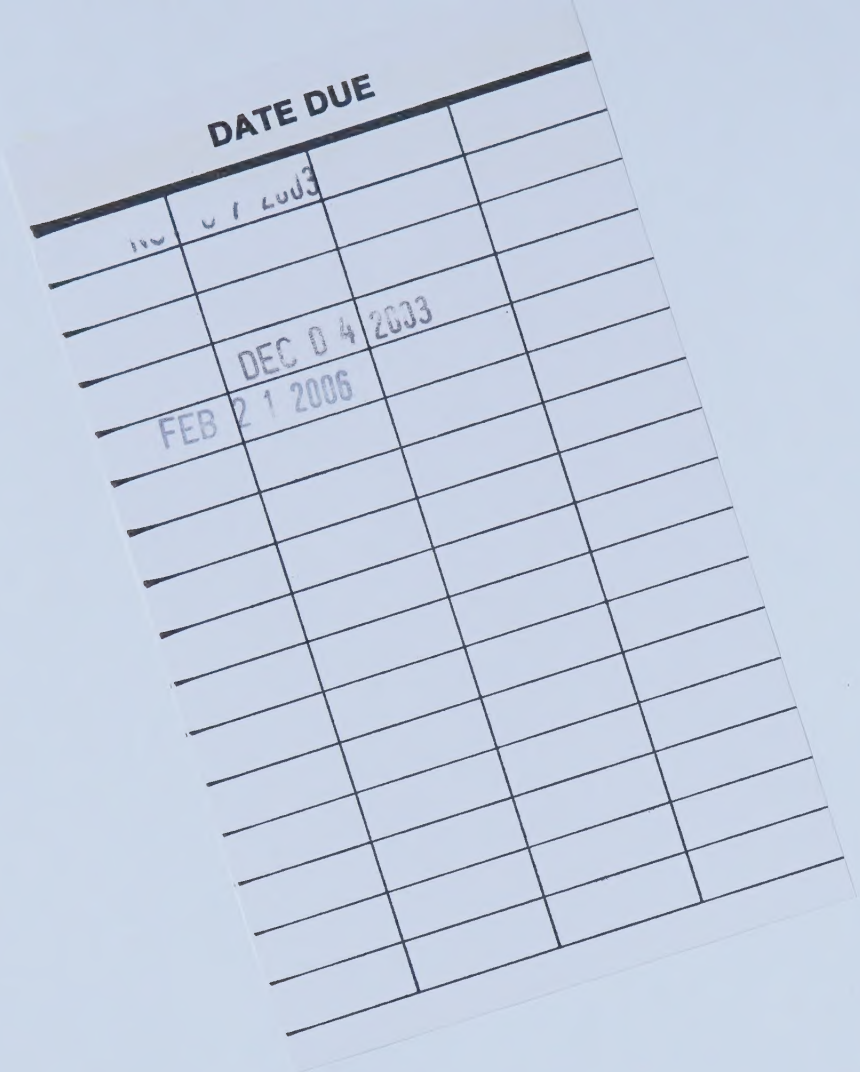
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Tuesday, September 28th

7:15 - 7:45 AM Registration

7:45 - 8:00 AM Bus Loading from Saskatoon Inn Lobby

8:00 AM Field Tour Departure (no delays)

7:00 - 10:00 PM Wine and Cheese, Registration

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7:30 **Registration**

8:00 - 8:05 **Introductory Remarks** – Saskatchewan Room 'B'
Tracy Patterson (CLRA) and Theresa Salamone (SEIMA) n/a

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Awards

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Saskatchewan Policy

Surface Lease Policy and Seismic Activity on Agricultural Crown Lands*

Wilf Pyle, Saskatchewan Agriculture & Food (SAF), Lands

Interest in gas and petroleum development on Crown agricultural lands has expanded greatly in recent years. Today there are over 4500 active surface lease agreements, several hundred easements and seismic authorizations typically top the 1000 mark each year. These bring in revenue of about five million dollars annually which represents about twenty percent of total branch revenue in any one year.

The branch is a participant in the Saskatchewan Petroleum Industry Government Environmental Committee and posts the reclamation guidelines developed by this group on the SAF Internet site at www.agr.gov.sk.ca. Industry members are urged to use these guidelines in establishing operating procedures on Crown lands. In addition to these there are certain policy procedures that are necessary and will form the first part of this paper. Seismic entry conditions, local contacts and charges are reviewed. The Petroleum and Gas Surface lease agreement is discussed and special reference is made to the environmental requirements outlined in the lease agreement. Prescreening activity and land use restrictions are briefly described and the relevant regulations are covered to provide a quick overview of reclamation and restoration requirements on Crown agricultural lands.

History:

- Lands Branch does not regulate the oil and gas industry must think of us as one big farmer.
- Regulations simply set out the manner in which the department can respond to the developmental needs of the industry.
- Number of seismic authorizations provided in 1973 – 5. Number last year - 230
- Number of surface oil well sites in 1973 – 707. Number last year - 4120

I. Seismic Activity on Agricultural Crown Lands Policy

A. Purpose

To provide a procedure to be followed by companies conducting seismic operations on agricultural Crown lands.

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* Presented at the 24th Annual Meeting of the Canadian Land Reclamation Association held jointly with the Saskatchewan Environmental Industry and Managers Association, Saskatoon, Saskatchewan, September 28-30, 1999.

B. Conditions

Where the land is under lease or sale agreement, companies conducting seismic work must obtain prior approval from the Department regarding wildlife habitat and environmental concerns. The company must then negotiate compensation for right of entry, adverse effects, and nuisance and productivity loss with the lessee.

Where land is not under lease or sale agreement, companies conducting work must obtain approval from the Department prior to entry. Payment to the Department for seismic work shall be $700 per mile on cultivated land and $400 per mile on grazing land. The charge for access only shall be $300 per mile. There shall be a minimum charge of one half mile per quarter.

3. Seismic work must be conducted in accordance with the guidelines for Seismic Activity on Crown lands in Saskatchewan.

C. General

Other Damages

Compensation for damages to crops, fences, etc. is not included in the above. The company responsible for the damages is required to pay for such damages directly to the lessee as they occur.

D. Process

Contact the regional office where a seismic agreement or authorization is made available to the applicant.

There are two ways to proceed. Ten days before the start of exploration the company representative brings a copy of the seismic plan to the regional office for review. The company must provide a valid Energy and Mines authority number and the full name of the company undertaking the exploration.

Our staff will then search for any reservations attached to the various Crown lands. For the purposes of this policy and clarity for the industry water bodies are considered Crown lands.

Where reservations are present the company must deal with those reservations. Most common is the restriction under the *Habitat Protection Act*, which affects some four million acres of Crown agricultural lands.

Saskatchewan Environment and Resource Management (SERM) is then advised and SERM will provide an approval conditional to the acceptance of certain restrictions relating to damage to the environment, disturbance and protection of certain plant and animal species.

The second method for processing the seismic request is for the company to have an account on the Crown Land Management System and use this to access the information regarding reservations and lessees. This is then summarized by the company and accompanies the initial request for seismic authorization.

Pay the fees per policy at the time of authorization.

An Overview of Operating Conditions:

The following lists the operating conditions common to authorizations to undertake exploration on Crown agricultural lands. The concepts behind these conditions were developed with full industry input in 1995 through the Saskatchewan Petroleum Industry/Government Environmental Committee (SPIGEC) process.

1. **FOREST ACT**

Permits issued under the authority of *The Forest Act*, "shall expire not later than March 31st next following date of issue." - (Section 15 of The Forest Regulations)

2. **TREE REMOVAL**

New cut lines are not to exceed eight meters in width, unless otherwise approved, and in all cases every attempt must be made to minimize line width. Debris from any clearing must be windrowed with five-meter breaks every 100 meters and at all recognized game and livestock trails.

4. **MAXIMUM WIDTH**

Maximum width of seismic line right-of-way is eight meters; all work and vehicular traffic is restricted to this right-of-way except where necessary to avoid environmentally sensitive terrain such as steep slopes or wetlands (steep refers to any slope where mineral soils will be exposed from travel). Where deviations are necessary, the shortest, the most direct route must be used, or the route of least environmental impact. If wet or thawing conditions exist, all vehicle activity must cease on native grasslands, if rutting could occur.

5. **NO MATERIAL**

No material is to be pushed into standing timber. All leaning trees are to be removed from standing timber by hand cutting, limbing to lie flat and, if not salvaged, "bucking" into sections maximum 2.5 meters in length.

6. OBSTRUCTING TRAILS

Obstructing traveled trails is prohibited.

7. DOG LEGGED

Where tree/shrub removal is authorized, lines are dog legged a minimum of 45 meter back from the edge of the right of way at all road, trail and stream crossings, intersecting seismic lines and points of access, and every 400 meters of seismic line where natural topography.

8. EXPLOSIVE DEVICES

The use of explosive devices is prohibited in or on any open or ice covered fish bearing water body. Precussionary devices are permitted only with special approval from the permitting authority. (Saskatchewan Environment and Resource Management Regional Co-ordinator, Oil and Gas Development.)

9. SPECIAL APPROVAL

Special approval may be granted for shot holes to be drilled in non fishbearing waters (via Saskatchewan Environment and Resource Management Regional Co-ordinator, Oil and Gas Development) provided the proponent agrees to fully and properly plug all holes from bottom to surface with bentonite, prior to taking the shot(s). Such approval must be obtained prior to any work occurring in/on the water body.

10. MERCHANTABLE TIMBER

Unless waived, all merchantable timber is to be salvaged by felling with a power saw (or mechanical harvester) limbing and skidding to locations specified by Saskatchewan Environment and Resource Management. Merchantable refers to all softwoods capable of making at least one 5 meter piece to a (size, 80mm, 100mm or 150mm) top diameter, inside bark, and all aspen capable to making at least one 5 meter piece to a (100mm or 150mm) top diameter inside bark. Saskatchewan Environment and Resource Management must be advised of the quantity and locations of salvaged timber.

11. EQUIPMENT TRANSPORTED

Equipment is to be transported around creeks, not walked through, in any situation where there is an existing crossing within 1 km in either direction. If no such crossing exists SERM's Regional Co-ordinator, Oil and Gas Development is to be contacted for direction.

12. SNOW BRIDGING

Snow bridging across streams may be permitted provided all material is clean and free of debris. The company must not alter the streambed. All introduced material must be removed from the streambed immediately upon completion of the line, or as otherwise authorized.

13. **SHORELAND ALTERATION**
If any stream, creek or river, is to be crossed, other than at existing structures, or if culverts or bridges are required, a Shoreland Alteration Permit must be obtained from Saskatchewan Environment and Resource Management.

14. **FORESTED SITES**
On forested sites where erosion may occur due to soil type, or grade, slash must be rolled back, spread and walked in. Additional site specific requirements will be determined by the leasing or permitting authority.

15. **LIMITED HABITAT**
As trees are a limited habitat in this area, tree removal is prohibited unless authorized by SERM. Saskatchewan Agriculture and Food and Resource Management are to be notified immediately of any changes to the proposed program. This includes any work not completed as per application. If applicable the Forest Management Licence Agreement holder must also be notified of any program changes.

17. **ENVIRONMENTAL MONITOR**
Due to environmental considerations present on this program, an environmental monitor, approved by Saskatchewan Environment and Resource Management regional office must be present for the duration of this program. The appointed Environmental Monitor must have the experience and be given the authority to halt work or direct changes as may be required to minimize environmental impact.

18. **MONITORING REPORT**
Within one month of project completion, two copies of an environmental as-built monitoring report are to be submitted to the Saskatchewan and Environment and Resource Management Regional office.

19. **FLOTATION EQUIPMENT**
In environmentally sensitive areas flotation tired equipment is required (companies must follow pertinent clauses within, Guidelines for Conducting Seismic Exploration on Environmentally Sensitive Terrain in Southern Saskatchewan, Saskatchewan Environment and Resource Management.

20. **WILDLIFE HABITAT**
On *Wildlife Habitat Protection Act* lands or environmentally sensitive Crown lands, where tree/shrub removal has been authorized, seismic lines must be hand cut unless

otherwise stipulated. On D. programs source lines are restricted to not less than 200 meters apart unless otherwise approved, and can not exceed 2.2 meters in width. Receiver lines are restricted to not less than 100 meters apart unless otherwise approved, and can not exceed 1.5 meters in width.

21. **SLASH**

Unless otherwise specified by Saskatchewan Environment and Resource Management, the operating company must roll back and spread "slash" on *Wildlife Habitat Protection Act* lands. This clause is not needed unless SERM advises.

22. **UNIQUE CLAUSES**

The following temporary measures are required to control erosion and otherwise control damage until a restoration plan can be prepared and approved. A description of the activity necessary to protect the soil or prevent vegetative damage.__

II. Crown Lands Petroleum and Gas Surface Lease Policy

A. Purpose

To outline the procedure to obtain a surface lease for the purpose of exploration or developmental drilling for petroleum and natural gas.

To outline rental adjustments for lessees of agricultural Crown land.

To outline endorsement requirements of surface leases issued by the purchaser of agricultural Crown land.

4. To provide environmental guidelines for companies developing well sites compressor and metering stations, access roads and easements on agricultural Crown land.

B. Terms and Conditions

1. Vacant Land or Land under Lease Contract

Where land is under lease or vacant, development companies are required to obtain a surface lease from the department before entering onto the land. Prior to locating and surveying sites on lands under lease, the company must contact the lessee to discuss proposed sites and to obtain access to the lease. In cases where entry is refused, the department will identify any legitimate concerns of the lessee and mediate with the company to resolve these concerns.

The Department will calculate surface lease rentals in accordance with The Surface Leases (Petroleum and Natural Gas) Compensation and Rental Regulations.

Agricultural lessees will receive an annual rental adjustment, which acknowledges the presence of a petroleum or natural gas wellsite and/or roadway.

Rental adjustments will be as follows:

$100 per wellsite or wellsite with roadway or roadway alone.
(b) Maximum consideration to be not greater than 30% of agricultural leases rental.
(c) In the case of new wells, maximum consideration will be no greater than 100% of the
agricultural lease rental.

2. General Conditions for Developers Entering Upon Vacant Land or Land under Lease Contract:

Companies must contact the Regional Office of Lands and Regulatory Management and make application, at least, ten (10) working days prior to expecting entry. As part of the application, companies are responsible to contact all agencies and address any reservations.
Applications for wellsite, access roads and easements must be accompanied by a survey plan for the project. Existing trails, roadways, seismic lines or natural clearings should be utilized whenever possible.
The Exploration Company must advise the department of the name and address of the parent company. The parent company and any sub-contractors are equally responsible for operation and development of a project.
Companies are responsible for damages to all improvements including fences, gates and crops. Compensation for damages is to be paid directly to the lessee.
No traveled trail is to be obstructed.
All contractors and sub-contractors are to be provided with a complete set of these conditions.
All refuse is to be removed to a designated land fill site. None is to be buried or burned on site.
All access routes and sites are to be marked indicating the company name.

3. Land Under Sale Contract

On lands under a sale agreement, the purchaser may give a surface lease to the Development Company, provided the department endorses the lease. Endorsement will be given on the condition that surface lease rentals will be remitted to the department for application against the purchase agreement.

4. General

In addition to surface lease rent paid to the department, the Development Company is responsible to pay the agricultural lessee(s) for damage outside of the leased area. The department will not grant a release where there is any outstanding claim for damages.

III. Surface Lease Fees and Rentals

Description	Amount
1. First Year Development Fee: (wellsites, roadways, compressor, separation or battery sites)	
(a) cultivated land	$597 per acre
(b) pasture land	506 per acre
2. Annual Surface Lease Rental: (wellsites, roadways, compressor, separation or battery sites)	
cultivated land:	
first 3 acres	597 per acre
each subsequent acre	209 per acre
(Minimum fee is for 2 acres)	
(b) pasture land:	
first 3 acres	506 per acre
each subsequent acre	162 per acre
(Minimum fee is for 2 acres)	
3. Multiple Well Heads	100 per head
4. Access Roads, First Year Development Fee	
cultivated land:	
first 3 acres	530 per acre
each subsequent acre	332 per acre
existing trails	110 per acre
pasture land:	
first 3 acres	425 per acre
each subsequent acre	271 per acre
existing trails	110 per acre

5. Access Roads, Annual Surface Rental

cultivated land:	
first 3 acres	304 per acre
each subsequent acre	209 per acre
(b) pasture land:	
first 3 acres	235 per acre
each subsequent acre	162 per acre

Description	Amount
Easements (one time charge)	
(a) cultivated land	547 per acre
(b) pasture land	506 per acre
7. Temporary Work Space	
(a) cultivated land	273.50 per acre
(b) pasture land	253 per acre

Process:

The process is similar to the seismic authorization process.

Interesting Regulations Relating to Petroleum and Gas Surfacing Leasing

Here are some recent changes in regulations under the Lands Act that are of interest to developers and seismic operators that affect Crown agricultural lands. They cover changes that provide increased compensation to agricultural leaseholders and clarify restoration requirements on any sites utilized by the industry. Many of these have formed part of policy and standard practices for several years and should create no new concerns for the development side of the petroleum industry.

In Saskatchewan compensation is paid to the agricultural lessee where a Petroleum and Gas Surface lease agreement comes into affect. Technically speaking the land is withdrawn from the associated agricultural lease while the petroleum and gas surface disposition is in effect. Every holder of an agricultural lease from which land has been withdrawn for the purposes of a petroleum and gas surface lease is entitled to receive a one-time payment of $200.00. When more than one well is drilled the agricultural leaseholder is entitled to receive $200.00 for the second well and $200.00 for each subsequent well. This compensates the agricultural lessee each time a new well is developed on an existing site. If there are two or more producing wells on the land the agricultural leaseholder is entitled to an annual rental reduction of $100.00. These

reductions for the agricultural lessee are held to a maximum of 30% of the annual rental charges payable on the agricultural lease.

In addition to the above compensation payments, the department will credit the agricultural lease holder for any crop loss suffered by the agricultural lessee due to the withdrawal of the land for the petroleum and gas lease. Compensation is limited to the amount paid by the petroleum and gas surface leaseholder to the department as determined by the department and the surface leaseholder.

Other new protection conditions are now also established in regulation. At the time of application for a petroleum and gas surface lease the developer must file a development plan with the department. While this has been an informal process in the past the plan must outline drilling location, construction, restoration or other development activities. The goal is to have a clear understanding of the impact the development will have on the natural area. As well, it protects wildlife and habitat now and into the future. Agricultural lease land regulations are now very clear on the process of abandonment and the surrender of any surface lease. Wells must be abandoned in accordance with the Oil and Gas Conservation Regulations of 1985. This means all holes must be plugged, the site clean and evidence that any pollutant that was placed on the site by the developer has been removed in an acceptable way. Restoration is spelled out to include a plan of restoration with the goal of attaining as nearly as possible a surface condition similar at the time of lease development or to an approved level. Surface leaseholders remain liable for rental charges where pollution and restoration issues are outstanding.

For seismic operators the regulations have been clarified to allow the Crown to now provide permission for entry to carry out surface operations designed to determine the extent of petroleum and natural gas deposits. Companies must deal directly with the agricultural lessee and address any legitimate agricultural concerns the agricultural lessee might have. Where this proves difficult the Crown can now support the request for surface access.

Lease Conditions and Restoration Criteria on Saskatchewan Agriculture and Food Land*

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Abstract

Saskatchewan Agriculture and Food (SAF) manages about 8 million acres of crown native rangeland, the majority of which is under long-term agricultural disposition for grazing. Many other land-uses occur including but not limited to oil and gas explorations and development, roads, utilities and sand and gravel extraction.
SAF supports these other land uses based upon the following principles:

- Orderly and efficient resource management though proper planning and development
- Environmental conservation and protection as an integral component in the planning and development process.
- Conservation of Saskatchewan=s remaining natural rangeland
- Minimal overall extent of land surface disturbance
- Restoration to pre-development conditions
- The use of native plant materials when reseeding or revegetation is required as part of site restoration.

SAF's main publication governing restoration activities on native agricultural crown ranglelands is titled "Restoration of Saskatchewan's Agricultural Crown Rangelands. Guidelines and Procedures for Developers" and is found on the SAF internet site at www.agr.gov.sk.ca. This document outlines specific requirements that govern the development of restoration plans needed prior to development as well as restoration statements, upon abandonment and requesting a release. Additional publications found at the SAF internet site deal with restoration on cultivated land, spills and contaminated sites, and assessment procedures.

The guidelines and procedures for SAF land were developed in cooperation with industry and reflect SAF's mandate and principles. They also incorporate Saskatchewan Environment and Resource Management's (SERM) process of project proposal screening. under the Environmental Assessment Act. The guidelines and procedures are standard

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* Presented at the 24th Annual Meeting of the Canadian Land Reclamation Association held jointly with the Saskatchewan Environmental Industry and Managers Association, Saskatoon, Saskatchewan, September 28-30, 1999.

throughout the province but they are designed to promote site specific development and restoration. The required restoration plan will also meet the requirements of SERM as part of the project proposal so duplication is not required.

Restoration plans are required in order to ensure minimal disturbance during development, protect rare habitats, flora and fauna, prevent the introduction of invasive non-native species and allow for additional restoration techniques as required on a site specific basis. The main measure of final site restoration is the comparison to pre-development or adjacent site conditions. Restoration criteria focus on live vegetation cover and distribution on the site; topsoil texture and depth; and overall landscape including drainage, erosion and contour.

The live plant cover should be 65% of pre-disturbance or adjacent site conditions should reflect the seed mixture or other procedures used for revegetation.
No noxious weeds are allowed as specified under the Canda Seeds Act and the Saskatchewan Noxious Weeds Act as well as additional species as outlined in SAF's publication "Restoration of Agricultural Crown Rangelands."
Admixing of topsoil and subsoil is not permitted.
Soil texture must be consistent with pre-disturbance or adjacent site conditions.
The addition of off-site topsoil or mixing of drilling by products is not permitted.
Replaced topsoil depth must be 70% of pre-disturbance or adjacent site conditions.
Drainage, erosion, contour and stability must all be consistent with pre-disturbance or adjacent site conditions.

Developers are required to submit a restoration statement documenting these criteria complete with site photographs prior to SAF inspecting a site for release purposes.

The overall goal of SAF is to promote better communication with developers and to streamline the process for exploration and development. By working with industry on an ongoing basis, procedures, guidelines and criteria can be better communicated and updated in order for a more efficient approval process and to ensure environmental conservation and protection.

Environmental Liability and Contaminated Site Management in Saskatchewan*

Victor Chang, Saskatchewan Environment and Resource Management

In response to recommendations made by the Contaminated Sites Liability Advisory Group (CSLAG) regarding the management of contaminated sites in Saskatchewan, Saskatchewan Environment and Resource Management (SERM) has, as a first step towards meeting the CSLAG objectives, developed a strategic approach as described in a paper entitled "Environmental Liability and Contaminated Site Mangement - A Strategic Approach". The paper was prepared based on CSLAG principles and was developed within the existing legislative framework. The strategic approach explains the current situation surrounding environmental liability and contaminated site management, provides a snapshot of current policy/legislation and is to be used as a basis for any required policy or legislative changes.

The strategic approach released on October 23, 1998 was prepared to clarify SERM's policy and incorporate principles and recommendations from the "Report of the Minister's Advisory Group on Contaminated Site Liability in Saskatchewan" that was received by the Minister in May 1997. The proposed process outlined by the strategic approach should be viewed as a significant step towards a fair, efficient and practical system for dealing with complexities involved in contaminated site management.

Uncertainty regarding environmental liability has been a concern during the 1990's. During cleanup of contaminated sites, there is always the issue of "how clean is clean", "who is responsible" and "how much liability they must bear". This uncertainty has placed a barrier to redevelopment of properties, especially when property changes hands. Financial institutions are reluctant to release funds, and purchasers and local municipalities have been wary of becoming involved in potentially contaminated sites. The Canadian Council of Ministers of Environment (CCME) endorsed a set of principles in 1993 to facilitate the development of provincial models and legislation for contaminated site liability. The CCME principles included the concepts of: polluter pays; fairness; openness, accessibility and participation; beneficiary pays; and sustainable development.

CSLAG was appointed in early 1996 and consisted of members from government, non-government organizations, the Saskatchewan Association of Rural Municipalities, the Saskatchewan Urban Municipalities Association (SUMA), industry, the Canadian Bar Association, the Canadian Federation of Independent Business and the financial sector. The CSLAG report made recommendations based on the application of CCME principles

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in Saskatchewan, the identification of contaminated sites, cleanup requirements and responsibility for liability relating to site cleanup. SERM is attempting to meet the objectives of CSLAG's report by working within the existing legislative framework and enhancing and clarifying existing policies. The strategic approach lays out a framework for identifying, allocating responsibility and cleaning up contaminated sites and is intended to provide clarity on the issue of environmental liability and contaminated sites.

The CSLAG report recommended the development of a risk based cleanup guidelines with fault based apportionment for liability and orphan site funding. This strategic approach has adopted the ideas of risk based guidelines and orphan site funding but utilizes voluntary instead of fault based apportionment of liability. Policy and legislation currently in place supports risk based guideline development and voluntary apportionment of liability. Implementation of fault based apportionment of liability, as recommended by CSLAG, would require major legislative change and could result in a more complicated system than required. Similar to the approach recommended by CSLAG, a five step contaminated site management process is defined by the strategic approach for the determination of cleanup procedures, liability and responsibility. The five steps are site identification; identification and notification of potentially responsible parties; allocation of liability (voluntary or directed); remediation planning; and site clean-up and sign-off.

The strategic approach will be monitored, as part of an incremental process, to point the way to any future changes in the approach, policy or legislation. SERM is monitoring how well the model addresses concerns surrounding environmental liability and contaminated site management. Comments and reactions will be taken into account during SERM's impending comprehensive review of environmental protection legislation.

Contaminated sites without responsible parties are known as orphan sites. In support of this strategy, SERM is also attempting to address the issue of orphan sites. SERM's policy has a pollution prevention focus and actions through existing licensing processes, environmental assessment processes, legislation such as *The Hazardous Substances and Waste Dangerous Goods Regulations* and *The Mineral Industry Environmental Protection Regulations* will assist in preventing creation of additional orphan sites. SERM recognizes that existing orphan sites will continue to be identified. SERM is exploring the applicability of sector funds or alternatives for addressing the issue of orphan sites, such as in the downstream petroleum sector.

The strategy also highlights who would NOT be held responsible for cleanup, such as innocent purchasers and municipalities if they did not cause the contamination. Recent litigation (*Busse Farms Ltd v. Federal Business Development Bank)* has provided further insight in the area of potentially responsible parties. Clarification in the area of potentially responsible parties allows purchasers, financial institutions and municipalities to feel

more at ease when dealing with contaminated sites. Parties that did not cause or contribute to the contamination are not held responsible for cleanup. As a result of this strategic approach, municipalities, such as the City of Moose Jaw have begun looking at approaches to dealing with properties under their jurisdictions.

Comments received regarding the overall process have been positive. The strategy provides clarity surrounding the contaminated site management process in Saskatchewan for government officials, industry personnel, law professionals, financial officers and the general public.

Environmental Liability and Contaminated Site Management-A Strategic approach is posted at **http://www.serm.gov.sk.ca/protection/liability**

Alberta Policy

Development and Status of Reclamation Certification Criteria in Alberta*

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Abstract

Alberta's Environmental Protection and Enhancement Act requires operators to conserve and reclaim land and to obtain a reclamation certificate. The government, in cooperation with industry and other stakeholders, has developed and published reclamation certification criteria for wellsites and for railways. Criteria are being developed for pipelines, borrow excavations, sand and gravel pits, and other activities. The criteria measure the success of industry's efforts to return disturbed land to equivalent land capability. Factors such as: (1) activity type and size, (2) age of the disturbance, (3) geographic location, (4) need for consistency and at the same time flexibility, (5) need for equal treatment between and within industries, (6) administrative and technical simplicity, and (7) stakeholder views are considered when developing the criteria. In 1998, Alberta's Reclamation Inspectors certified over 2400 wellsites.

This paper describes the development process for criteria with specific emphasis on the wellsite criteria, which underwent an extensive public review in 1998.

Introduction

Alberta's Environmental Protection and Enhancement Act (EPEA) came into force on September 1, 1993. EPEA requires operators of specific industrial developments to conserve and reclaim land and to obtain a reclamation certificate. The activities include coal mines, oil sands mines, quarries, sand and gravel pits, pipelines, wellsites, railways, roadways, peat operations, and transmission lines.

The objective of reclamation in Alberta is the return of equivalent land capability. This means that the ability of the land to support various land uses after conservation and reclamation is similar to the ability that existed prior to an activity being conducted on the land, but that the individual land uses will not necessarily be the same. The intent is to retain the original range of land use options for future generations. At the same time, there is flexibility to change the capability for various land uses (e.g., good forestry capability can be replaced by good wildlife capability).

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The Conservation and Reclamation Regulation gives the Director the ability to establish criteria for certification. It also lays out the information that must be submitted with an application for a certificate and the process for certification.

To date we have developed and published criteria for wellsites (Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update – C&R/IL/95-3) and for railways (Reclamation Criteria for Abandoned Railways – C&R/IL/96-3). Criteria for borrow excavations (a new class of pits), pipelines (Fedkenheuer et. al. 1999), sand and gravel pits, and others will be developed in the future.

Need for Criteria

For many years, reclamation certification was conducted without any written criteria. Industry and government staff relied on general understanding and professional judgement to determine success.

Developing and publishing criteria provides a number of benefits to all stakeholders:
Criteria provide industry with a clear understanding of the government's expectations for reclamation. This allows industry to plan their activities with the "target" in sight.
Criteria allow reclamation success to be objectively measured.
Criteria allow government, industry and consultants to train their staff in the certification process and requirements. Training leads to understanding and consistency.
Finally, criteria form the basis for resolving conflicts between the interpretations of industry, landowners and the government inspector.

General Criteria Development Process

Alberta Environment develops criteria jointly with stakeholders in industry and the affected publics. There are two basic processes that we have used to develop criteria. Each has its strengths and weaknesses (Table 1).

Table 1. Strengths and Weaknesses of Criteria Development Processes.

Process	Strengths	Weaknesses
Stakeholder committees prepare first draft of criteria	• Stakeholder buy-in from the start of the process • Better for dealing with "principles" and "process" issues • Provides opportunity for better "out-of-the-box" solutions	• Generally, longer first draft development time required • Harder to deal with "technical" issues as some public members may not have a technical background

In both cases, when the draft is finished, it is sent for review and comment to a broader list of stakeholder groups. These groups represent industry and landowners that have a direct interest in land reclamation. The criteria are redrafted by government (possibly with referral to the committee) based on their comments and are published. The criteria are then tested for a period of time. Periodic reviews of the effectiveness of the criteria are conducted and revisions made if necessary.

Who are "Stakeholders"?

The stakeholder committees are made up of representatives from government, industry and the public. Generally, the members are chosen by their respective associations (e.g., Canadian Association of Petroleum Producers and Small Explorers and Producers Association of Canada select oil and gas industry members and Alberta Surface Rights Federation selects public members).

As noted above, we consult with associations or organizations that represent stakeholder groups rather than with individual companies or persons. Our experience over the last several years has shown that these stakeholder groups do not always represent the broader target groups. In some cases, they do not even represent their own members' views. This makes it difficult for all parties to know if consensus decisions within the committee will be accepted and implemented by the broader target groups.

Wellsite Criteria Development Process

In 1993, government staff started to develop narrative and numeric criteria that would clearly define reclamation expectations for wellsites. The development was in response to increasing requests from industry for a clear description of the certification criteria being used. They were concerned that different inspectors were using different yardsticks to determine success.

Draft criteria were prepared by government and reviewed by industry. The result of these deliberations was the Reclamation Criteria for Wellsites and Associated Facilities (LCRC/IL/93-2). These criteria were field tested for one year and their success was evaluated in a government/industry/public stakeholder workshop (Mahnic et. al. 1993).

The input from the workshop was used by a government/industry committee to revise the criteria (Reclamation Criteria for Wellsites and Associated Facilities – C&R/IL/94-1). The revised criteria were sent for review by industry and public stakeholders. Again, there was no direct public input in the development phase of the criteria, only in the review phase.

The revised criteria were field tested for another year. The government/industry committee was reconvened and the 1995 criteria were developed and published (Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update – C&R/IL/95-3). Again, there was no direct public input in the development phase of the criteria, only in the review phase.

The revised criteria have been in use since April 1995. Considerable experience has been gained by government inspectors, oil and gas industry staff, consulting professionals and landowners. This experience has allowed the parties to identify problems with the criteria and with their implementation (i.e., the policies and procedures that establish the framework for certification and criteria use).

In February and March 1998 the government initiated a public consultation process to get input from landowners, industry, consultants, and government staff on two primary issues:
Should the government change the wellsite certification process on private land from a mandatory on-site inquiry by a government inspector to a random audit of a percentage of sites?
Are changes required to make the criteria better, and if so, what changes are suggested?

Ten meetings were held across the province, with the aid of a consultant skilled in public consultation (Bill McMillan, Equus Consulting Group). Written submissions were also solicited from those who could not attend the public meetings. Approximately 830 people participated in the public meetings and an additional 51 written responses were received.

A Steering Committee, made up of government, industry and landowners, was established to review the feedback received from the meetings. The consultant provided facilitation and secretarial support for the Steering Committee. The Steering Committee decided that it would address the "process" issues around certification. They established a Technical Subcommittee (again made up of government, industry and landowners) that would address the "technical" criteria issues.

In May 1998 the Steering Committee released a summary of the input from the meetings and written responses. The summary was sent to all meeting participants. In June 1998 the Ministers of Environmental Protection and Agriculture, Food and Rural Development sent a letter to all meeting participants indicating that the proposed audit process would not proceed at this point in time. This decision reflected the almost unanimous input from stakeholders at the public meetings.

From June 1998 to March 1999 the Steering Committee continued to finalize recommendations to the Ministers addressing the "process" issues. A Final Report of the Steering Committee, containing 16 recommendations, has been prepared and sent to the

Ministers for endorsement and release to all meeting participants. The majority of the recommendations centre around improved communication between parties, especially between industry and landowners. Industry has been very proactive in developing improved communication tools (e.g., a template letter that will be sent by a company to the landowner informing him that a well is being abandoned and reclaimed and the activities that will take place on his land).

The Technical Subcommittee met a number of times, reviewed the input from the meetings, and reviewed various alternative models for evaluating reclamation criteria. The technical review of the criteria has proven to be more difficult than originally envisioned. No recommendations have been made as yet. The 1995 criteria remain in effect for the 1999 field season.

Development Process for Other Criteria

Other criteria were developed or are being developed using various versions and hybrids of the development processes shown in Table 1:
The railway criteria were developed with industry and limited landowner/public involvement (Farmer's Advocate, Alberta Association of Municipal Districts and Counties).
Criteria for borrow excavations are being developed through a Steering Committee with industry, and limited public involvement (Alberta Association of Municipal Districts and Counties).
Criteria for pipelines are being developed with industry involvement.

Conclusion

There is no one criteria development process that is "best". Experience in Alberta suggests that where time is not an issue, involving stakeholders from the very beginning produces a final product that is supported by all stakeholders. They believe that they have been heard and listened to. This process will take considerable time, especially if there are complex technical issues to address or parties who are not familiar with the regulatory process around reclamation certification.

However, where time is a factor, having one party (usually government) produce a "straw dog" for industry and the public to review and comment on may be necessary. For this strategy to be successful, the authors must be prepared to accept more criticism of the first draft and be fully prepared to change it than if the draft had been prepared with all stakeholders. There will be stakeholders who feel that they haven't been properly consulted. This can be addressed by keeping the criteria a "living document" that can be revised at a later date with a more open process. Initial meetings in this second phase will have to leave time for stakeholders to air grievances about the first phase. Then work can proceed.

A compromise between the two approaches (used in the development of the railway criteria) is to have a multi-stakeholder committee but get their approval for one party to prepare a "straw-dog" for review.

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Developing Pipeline Reclamation Standards in Alberta (Canada) *

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1. ABSTRACT

Development of Alberta's oil and gas industry has led to a proliferation of pipelines in the province. All Alberta pipelines require a reclamation certificate before the proponent is released of reclamation liabilities. This has led to much discussion of how to assess oil and gas wellsites and pipeline reclamation success since the early 1980s. The requirement for reclamation certification is that land have equivalent capability to that which existed prior to the disturbance. The approach that has been used for wellsite reclamation success evaluation is a parameter by parameter comparison and pass/fail system. In this case each parameter must pass or the site fails. NOVA Gas Transmission Ltd. undertook, in late 1996, to put together a group of government regulatory and non-regulatory personnel, industry and third party individuals to develop a more integrated capability based evaluation system. Various approaches were field tested in 1997 and 1998. This paper reports on the process used, the field results and current status of the project.

2. INTRODUCTION

Most people are not aware of the presence of pipelines because they are generally buried and are rarely seen as the soil over them continues to support pre-disturbance activities such as agriculture, forestry, urban and rural communities, and wildlife habitat. As a result it may be a surprise that Mutrie and Gilmore (1995) estimated that Alberta has over 2,000,000 km of pipelines in the ground.

Concern about the environmental impacts from construction of pipelines has brought legislation governing their construction, operation and decommissioning. Within Alberta there was no legislated requirement for the reclamation of disturbed lands prior to 1963 when the Surface Reclamation Act was proclaimed (Brocke 1988). Ten years later, in 1973, the Land Surface Conservation and Reclamation Act was proclaimed. This new Act required that environmental protection and reclamation be part of the development planning (Landsburg and Fedkenheuer 1990). A review and approval system that included Environmental Impact Assessments and Development and Reclamation Approvals was subsequently implemented. Regulatory changes were made in 1983 and

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again in 1993 with the passage of the Alberta "Environmental Protection and Enhancement Act" (Alberta Environmental Protection 1994).

The 1993 legislation brought the requirement to return land disturbed by pipeline construction to an equivalent land capability at the time of abandonment. Equivalent land capability is currently defined as, "The ability of the land to support various land uses after reclamation is similar to the ability that existed prior to any activity being conducted on the land, but that the individual land uses will not necessarily be identical" (Powter 1998).

The requirement to have equivalent land capability at the time of application for a reclamation certificate brought the need to be able to measure equivalent land capability. Some documentation is required to enable the regulator to acknowledge that the area is suitably reclaimed and to release the

proponent from further reclamation liability, as well as to assure the public that a suitable reclamation job has been done. This documentation has been difficult to obtain agreement on and it has been the subject of much discussion since the mid-1980s. The definition of reclamation success and how to measure it was the topic of a workshop in 1992 (Mahnic and Toogood 1992). Following the workshop, focus shifted to oil and gas wellsite reclamation criteria development for several years where a parameter based checklist was developed and used. For these areas, specific individual parameters are compared on and off the wellsite and each must pass or the site fails.

There has been a desire by some to utilize this system for pipelines as well. Others have suggested using a capability rating system such as has been used in agriculture for many years. It is recognized that some modifications may be required to either system if they are to be applied to pipelines. These two approaches reached a stalemate in 1996. At that point NOVA Gas Transmission offered to take the lead in working to develop a land capability rating system to demonstrate what it might contain and how it might work better for pipeline reclamation assessment. This paper addresses the approach used and the results of the approach.

3. PROCESS

In 1995, as interest in reclamation standards for pipelines again began to increase, several joint government-industry working groups were established. In mid-1996, a version of the wellsite reclamation criteria was modified and tabled for consideration as pipeline reclamation criteria. As discussed earlier, the wellsite criteria are basically a parameter-by-parameter pass or fail system.

To deal with the issue of developing a capability-based assessment of pipeline reclamation, a varied group of people were required around the table. A group of people consisting of representatives from government regulatory bodies, industry and also some independent experts, was invited to participate. The group was formally named the NGTL (NOVA Gas Transmission Ltd.) External Soils Advisory Board and consisted initially of: Adolf Bruneski, Land and Forest Service, Alberta Environment; Jim Burke, NOVA Gas Transmission Ltd. (now J. D. Burke and Associates Ltd.); Dr. Al Fedkenheuer, NOVA Gas Transmission Ltd. (Chairperson); Heather Gerling, Public Lands Division, Alberta Agriculture, Food & Rural Development; Tom Goddard, Conservation and Development Branch, Alberta Agriculture, Food & Rural Development; Vasile Klaassen, PanCanadian Petroleum Limited; Len Knapik, Pedocan Land Evaluation Ltd.; Leonard Leskiw, Can-Ag Enterprises Ltd.; Dr. Anne Naeth, University of Alberta; Dr. Wayne Pettapiece, formerly with the Research Branch, Agriculture and Agri-Food Canada (now Pettapiece Pedology); Chris Powter, Environmental Sciences Division, Alberta Environment; and Rob Staniland, Talisman Energy Inc. Dr. Naeth and Len Knapik withdrew from the committee due to time availability constraints.

A key component of this board is members that are not directly involved in oil and gas from an industry or government regulatory perspective, e.g. T. Goddard and W. Pettapiece. They have brought both a practical and scientific perspective to the Board, as well as considerable experience.

The Board's primary short-term objective was to develop a pipeline reclamation evaluation tool. There was much discussion as to when this tool would be applied, either at post-construction or upon abandonment of the pipeline or at both times. It was agreed that the Board would focus on abandonment criteria which would be applied at the end of the life of a pipeline. In this way, the operator would know, in the planning stages of construction, what would be measured at the end. This would encourage good planning of soils handling and other environmental issues during construction in order to minimize the cost over the life of the pipeline.

Important components of the reclamation evaluation tool as identified by the Board were:

- scientific validity,
- identification of important environmental parameters,
- clear description of how to measure those environmental parameters.
- relatively easy usage,
- cost-effectiveness, and
- provision of reproducible results,

It was also a desire that time not be spent initially building new systems but to evaluate systems and processes already available. In the end, it was decided that a visual assessment as well as several others, one with a more detailed level than the visual, but

not requiring laboratory analyses, and another requiring laboratory analyses needed to be developed. As well, the Land Suitability Rating System (Agronomic Interpretations Working Group 1995) and a version of the wellsite reclamation criteria system (Wellsite Criteria Working Group 1995) were tested. Along with these systems, a landowner reclamation evaluation form was also developed.

Following agreement on the systems to use, the Board retained three senior consultants to take the systems to the field and evaluate their field performance. This was done in October and November, 1997. The consultants were sent to three central areas of the province and asked to employ the systems on five pipeline segments, chosen by representatives of the Board, in each area. The consultants were not to be on the same site at the same time, nor were they to discuss their findings with each other until after their reports had been submitted to the Board. One day was spent in the field by the Board and each consultant was visited at a different pipeline location. Subsequent to the receipt of the reports, three members of the Board undertook to summarize the consultant reports into one summary report.

The Board took the results of the 1997 field evaluation and the consultant recommendations and revised the evaluation tool into a three-step process for a re-test in the field season of 1998. One step was a landowner reclamation evaluation form that reflects the parameters being assessed by consultants. The other two steps were done by consultants. During Phase 1, three parameters under landscape (drainage, coarse fragments and microtopography), vegetation (cover, composition and vigor) and soil (color, texture and surface structure) must be met in order for the site to pass. If the area fails the Phase 1 portion, assessment must continue under a Phase 2 evaluation consisting of a more detailed soils assessment only.

The 1998 field study covered a range of ecological conditions in Alberta. This included approximately five pipeline sites in the dry Prairies (Brooks), salt-affected and clayey soils in the Parkland region (Vegreville and Grande Prairie), the southern Boreal (Lac La Biche), and the foothills Montane (Pincher Creek). All areas included both cultivation and grazing land uses.

The larger percentage of the direct funding of the consultants and other activities has come from
NGTL, with significant funding also coming from the Canadian Association of Petroleum Producers and more recently, Alberta Environment.

4. RESULTS

Accomplishments of the Board to date consist of: development of Board objectives, an evaluation tool framework, tool parameters, an evaluation process, completion of a field evaluation study in 1997 and 1998 (using three external consultants in each year), comparison of seven systems initially in 1997, comparison of selected modified systems

in 1998, development of a separate summary report of the 1997 and 1998 field studies, and completion of landowner reclamation evaluation forms.

Results from the 1997 field study were:

- Agreement on pass/fail results among the three consultants who visited the same sites was less than 45 percent in all of the reclamation evaluation systems tested in 1997, except for the Visual system where there was about 90 percent agreement,
- Across the 18 quarter sections in the study, the average topsoil depth was 16 cm (+/- 8 cm) both on and off the pipeline right-of-way. Topsoil depth recordings by the consultants reflected this natural variability as one consultant reported finding 10 to 26 cm of topsoil, another reported finding 10 to 19 cm and the third consultant reported 12 to 26 cm. These readings were all for the same 65 ha and were done by well-qualified soils professionals. Again, this was the natural variability in an agricultural field,
- Topsoil thickness alone is a poor indicator of reclamation success as systems that relied heavily on topsoil depth as a measure of reclamation success had failure rates of greater than 40 percent based on topsoil depth by itself,
- Removing the topsoil depth parameter resulted in failure rates of about 15 percent,
- The visual parameters caught about 73 percent out of 183 right-of-way transect failures. This means many of the failures were apparent to the evaluator before subsurface parameters were evaluated.

In the 1998 field study, line segments were evaluated in 32 quarter sections (160 acres: 65 ha) by each of three consultant companies in August and September by applying both Phase 1 and Phase 2 to all areas. Results of the study were:

- On 44% of the line segments all three consultants agreed whether the area passed or failed the Phase 1. Of the remaining areas, in 34% of the cases two of three consultants passed them and in the remaining 22%, two of three consultants failed them,
- In 66% of the Phase 2 assessments all three consultants agreed (all were passes), of the remaining line segments 28% were rated as passes by two of three consultants and 6% were rated as fails,
- There were no cases where an area passing Phase 1 was failed under the Phase 2 assessment. This implies this part of the system works as designed,
- Several weaknesses were identified including how to handle cases where the disturbed area was better than the control areas, flexibility in dealing with non-standard, and exceptional, circumstances and more clarity in the vegetation assessment.

In the part of this process where landowner input was sought, the following results were obtained:

- In the 1998 study, 94% of the 31 landowners contacted responded, with some encouragement, by filling out the forms evaluating reclamation success as they saw it for the study pipelines on their land,
- 72% of the line segments were rated as passes by the landowners,
- The landowner evaluation and the Phase 1 rating by all three consultants agreed on 72% of the line segments (15 "pass" and 6 "fail" ratings, respectively),
- On three line segments (10%) the landowners rated the area as "pass" and the Phase 1 ratings by all these consultants was a "fail".

5.0 CONCLUSIONS

The NGTL External Advisory Board has concluded that:

- The general concept of a land capability based, relatively rapid Phase 1 "screening" assessment and an "as required" more detailed Phase 2 soil evaluation is workable and appears to address the proper concerns and issues,
- The weaknesses identified thus far in the process are manageable and are currently undergoing revision,
- Landowners are willing to participate, there is generally good agreement between the landowner and consultant ratings, and the landowner evaluation form can be a useful first evaluation of pipeline reclamation, and
- Some form of orientation (training) sessions will likely increase the level of agreement among the consultant ratings.

The Board is continuing to pursue this approach and will likely recommend it be used on a trial basis for a year. If this approach is implemented, it will be important to review and revise the process, if necessary, based on its use and input by a wide variety of users, including members of the public.

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Alberta's Draft Native Plant Revegetation Guidelines*

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Abstract

The second draft of *Native Plant Revegetation Guidelines for Alberta* was released in June 1999 by the Native Plant Working Group. This multi-stakeholder committee has representation from provincial government agencies, various industries and non-government organizations. There is currently no legislation in Alberta that requires the use of native species in reclamation. However, the use of native species for reclamation projects in natural landscapes on public land can be required, if the surrounding land use and the revegetation objectives for the area warrant it. The guidelines provide a clear, consistent and integrated information package about using native plant materials where the revegetation goal is to re-establish a native plant community. The guidelines are not prescriptive. It is recognized that site specific circumstances have to be considered when planning revegetation projects. This paper reports on the process used to develop the guidelines and the major topic areas covered by the guidelines. The complete draft document can be viewed at **http://www.agric.gov.ab.ca/publands/nprg/**.

I. Introduction

1.1 Background

The use of native plants in reclamation has been recognized as important for protecting the integrity of Alberta's natural landscapes since the 1970's. The use of native grasses to revegetate wellsites and pipelines has been required on publicly owned prairie areas since 1990. The use of native species on disturbances in forested areas in the province is quite variable, depending on land use patterns in different regions of the province. With the increasing use of native species come concerns about inconsistencies in regulatory requirements, as well as concerns about seed purity and the potential for the introduction of undesirable plants. Costs of native plant materials are high and their commercial availability is often poor. There is also unease about movement of plant materials across large distances, as it might affect plant performance and the genetics of local populations.

In late 1997, land managers from Alberta Environment (AENV) and Alberta Agriculture, Food and Rural Development (AAFRD), who manage the Green (forested) and White

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(settled) areas of Alberta, respectively, met to discuss their concerns and to determine a course of action to address them. A decision was made to invite affected industry groups and interested non-government organizations to participate in the development of guidelines that would promote consistent and appropriate use of native plant materials on public lands.

Guidelines, rather than a formal policy, have been favoured for several reasons. First, the guidelines give direction but also provide much-needed flexibility and lead-time for development of supplies. Second, industry response to some other guidelines in Alberta has been very encouraging. For example, the Alberta Energy and Utilities Board information letter, Petroleum Activity on Native Prairie: Guidelines for Surface Disturbances (1996) has been implemented successfully. The oil and gas industry has been very responsive and continues to find innovative ways to reduce impacts. Third, the use of native plants in revegetation is still in its infancy. As new knowledge comes to light, it is easier to modify guidelines than to change policy or legislation.

1.2 Process

The Native Plant Working Group (NPWG) has representatives from various provincial government jurisdictions, the oil and gas industry, coal industry, seed industry, cattle industry and some non-government organizations. The members of the NPWG are: Heather Gerling, Public Lands Division, Alberta Agriculture, Food and Rural Development (Chair); Andy Etmanski (Coal Association of Canada); Elgar Grinde (Alberta Cattle Commission); Rob Kesseler, Land and Forest Service, Alberta Environment; Cam Lane, Land and Forest Service, Alberta Environment; Jim Lindquist, Public Lands Division, Alberta Agriculture, Food and Rural Development; Kerby Lowen, Canadian Seed Trade Association; Laura Morrison, Alberta Energy and Utilities Board; Michelle Pahl, Alberta Research Council; Ann Smreciu, Alberta Native Plant Council; Dan Smith, Public Lands Division, Alberta Agriculture, Food and Rural Development; Don Watson, Environmental Services Division, Alberta Environment. The following people had previous involvement in the process, or provided substantial review of the document: Terry Anderson, Canadian Seed Trade Association; Jeanie Bietz, Canadian Environmental Pipeline Association; Lorne Cole, Special Areas Board; Rick Ferster, Coal Association of Canada; Bernd Martens, Coal Association of Canada; Ian Proctor, Canadian Association of Petroleum Producers; Rob Staniland, Canadian Association of Petroleum Producers.

The first draft of the guidelines was released in November of 1998 to both academic reviewers and the general public. The comments received during this review were used to revise the document. The second draft was released in June 1999, and it will be used on a trial basis for the 1999 field season. The working group will prepare a final version using the comments and recommendations received during the trial period. The final document will be released in 2000 following government approval.

1.3 Objectives

The NPWG has developed the following objectives for the guidelines:

- To promote the use of native species in the revegetation of disturbed sites within native plant communities,
- To encourage the eventual establishment of native plant communities within native landscapes,
- To acknowledge the site specific role of non-native species to meet short-term revegetation goals or meet accepted land use needs.

II. Guidelines

The guidelines are not intended to be prescriptive. The working group recognizes that site specific circumstances, including land use objectives, have to be considered when planning revegetation projects. Many of the more prescriptive statements found in the first draft were deleted and will be treated in more detail in a companion document, *How to Revegetate Native Landscapes.* The anticipated publication date for this new book is June of 2000.

2.1 Planning

Public land managers in Alberta are stressing the importance of minimum disturbance to natural landscapes when planning industrial or commercial activities. Avoidance of rare or sensitive plant communities is often required. Industry has developed various techniques to reduce the area of disturbance and may have to time their operations carefully. Special equipment has been designed for projects to minimize damage or to promote better re-establishment of vegetation.

The use of native plants should be consistent with local and/or regional land use plans or objectives and the surrounding vegetation. The guidelines promote the use of native species only where appropriate. If the surrounding area is already dominated by non-native crops or there are problems in the local area with invasive non-native plants, it often does not make sense to plant expensive native plant materials.

Project goals need to be clearly understood. They can include, for example, erosion control, sustainable grazing, wildlife habitat, reforestation, maintenance of biodiversity and aesthetics. Revegetation planning may need to address potential conflicts in goals. In the past, erosion control has often been the only revegetation goal, with thick carpets of non-native grasses/legumes established on reclamation sites. Today, erosion control is still a primary goal on many sites, however, the species composition and seeding rates can often be adjusted to meet other project goals.

2.2 Plant Species Selection

The selection of appropriate native plant materials to fit site specific requirements and project objectives is critical to the success of native revegetation efforts. As a general rule, native species should be selected based on their compatibility with pre-disturbance plant communities. However, there are reclamation sites that are radically different from their predisturbance condition, with different soils, drainage and topography. In these cases, similar sites (if they exist) in the same Natural Subregion should be examined to see what native plants are performing well. Efforts should be made to source these plants. If this is not possible, then short-lived natives (from other Natural Regions) or non-natives can be used to stabilize reclamation sites on an interim basis, until local plants can reestablish on the site. On large sites, island plantings may be required to provide an adequate seed source.

Current thought is that a range of plant materials should be seeded to handle the range of growing conditions during establishment and to allow time to produce an increasingly diverse stand on the site through reversion and succession. This includes the use of multiple species, but can also include the use of different varieties of the same species and multiple age classes. Multiple planting events can also be considered, especially on large areas. Thought should also be given to the possible interactions of planted species, and the potential effects on project goals. For example, if reestablishment of shrubs or trees is a desired outcome, then the amount of grass planted should be minimized as much as possible.

2.3 Sourcing Native Plant Materials

The guidelines emphasize the importance of seed quality to both growers and buyers. Included in the guidelines document are appendices showing users how to interpret a seed testing certificate, as well as national and provincial lists of problem weeds are. Native seed lots should be free of prohibited, primary and secondary noxious weeds as defined by the *Canada Seeds Act*. Lots should also be free of restricted and noxious weeds designated by the Alberta *Weed Control Act* or by a local municipality.

One of the difficulties facing public land managers is the introduction of invasive species to natural landscapes because of the use of untested native seed mixes. Operators can be required to produce a seed analysis certificate for any native seed lot used on public land. Since 1996, AAFRD has had zero tolerance for specified invasive species that show up in native seed testing (AAFRD, 1996).

Seed testing can also assure buyers that the seed is viable, i.e. that it will germinate. Wild harvested seed typically has a lower percent germination than seed that has been cultivated. Some seed has a very low germination and more seed is used to achieve the desired results.

The source of native seed can have implications for performance on the reclamation site and there is considerable controversy over genetic effects of moving native plant materials over long distances. Rules about movement of native tree seed for the forest industry have been in effect for many years. There are no rules for any other native species. Most jurisdictions in North America are placing some kind of limitation on movement of seed. Alberta recognizes that definitive research on this topic is lacking and that, very likely, requirements are species specific.

The guidelines take a conservative approach until more information is available. They promote the use of seed whose genetic origin is from within the same Natural Subregion as the disturbance (Figure 1). If such seed is unavailable, users are directed to try using native plant material that has been performance tested in Alberta. If the performance meets project goals then the seed can be used, otherwise it is removed from the revegetation mix. Native plant materials used to reconstruct natural landscapes in Alberta should be not be sourced outside North America.

2.4 Supply and Demand

Synchronizing supplies of and demand for native plant materials is quite difficult. Lead times to produce commercial quantities of materials can vary from two to five years. Industrial project planners seldom have this kind of lead time. Growers would like to have some assurance that there will be a market for the materials they are producing. The guidelines attempt to bring some stabilization to supply and demand by providing two appendices.

One appendix lists native species that are commercially available at the moment; are currently in development for commercial supply or are considered priority species for revegetation projects in the future. Selections for the last category were based on: wide application (across several Natural Subregions), potential for erosion control, legumes, early successional plants or key components in various plant community types. Since this is a draft document, suggestions for additions or deletions (with supporting reasons) to this list are welcomed.

The second appendix is a listing of native species currently recommended for reclamation projects in various natural landscapes on publicly owned land in Alberta. These species are either currently available in commercial quantity or are considered to be key species that will be available commercially within a five year timeframe. This listing is intended to be a starting point only and users are directed to *A Guide to Using Native Plants on Disturbed Lands* (Gerling et al., 1996) for detailed plant or plant community information. AAFRD and AENV will update the appendix in the guidelines yearly. Public land managers should also be consulted to determine site specific requirements.

2.5 Wild Harvesting

The guidelines do not promote wild harvesting as a normal way of obtaining native plant material for commercial use. Significant and irreparable damage can be done through over-collection of plant materials from natural landscapes. Wild harvesting is necessary to obtain original genetic material for propagation purposes. Seed collection is allowed on public land in Alberta to obtain commercial volumes of seed for revegetating significant vegetation communities that would otherwise be replanted with unsuitable plant materials. A Termporary Field Authority (TFA) with conditions is required to collect native seed on public land.

Specific guidelines and procedures (adapted from ANPC guidelines) for this wild harvesting are included as an appendix in the document. Emphasis is given to getting appropriate permission, avoidance of rare plants/habitats, collection of ripe seed or cuttings and not whole plants, leaving sufficient seed behind for natural propagation and food for animals, and resting areas (minimum 2 years) between collections.

2.6 Site Preparation, Planting and Maintenance

A number of general guidelines are included in this section. The importance of good site preparation is emphasized. Many failures of native revegetation projects are due to inadequate preparation, particularly weed control. The existing seedbank and distance to cultivated areas are very important considerations when deciding on whether to use native species in the first place, what species to plant and what strategies should be employed during planting and maintenance.

Attention is drawn to the current practice of straw crimping (for erosion control) and the importance of inspecting the fields that the straw is coming from for weeds. Public land managers are starting to favour the use of annual crops over straw in some areas because of the ability to examine seed lots for weed content. Subsequent management of weeds on reclamation sites is also very important to ensure the sustainability of native plantings.
The potential benefits of non-persistent annual weeds, e.g., flixweed for erosion control, soil amelioration protection of native plants from grazing are pointed out. Too often these are unnecessarily sprayed, which removes reestablishing native forbs. The companion book in progress, *How to Revegetate Native Landscapes,* will provide much more detailed information on these subject areas.

2.7 Assessing Reclamation Success

Project planners and public land managers need to readjust their expectations when evaluating revegetation efforts in natural landscapes. Considerable time may pass before reclaimed areas look anything like, or blend into, surrounding areas. Early successional species may dominate reclaimed areas for long periods of time before late successional species become established. The extent to which project goals are met and the demonstration of a successional trend toward a desired native plant community should be considered when determining the success of a revegetation project. Monitoring and reporting of results is crucial to the evolution of better science for native plant revegetation.

III. Future Needs

The NPWG has identified future needs that require immediate attention:

- Development of "source-identified" tags to enhance the movement of appropriate native plant materials into revegetation projects. A committee established following last year's Native Plant Summit IV: Native Plant Production, held in Calgary, Alberta, is looking into this possibility with the Canadian Seed Growers Association.
- Development of joint government/industry support for a performance evaluation program for native plants from known sources.
- Support of ongoing native plant cultivar development programs.
- Development of knowledge about successional trends to assist in the determination of revegetation success.
- Development of rhizobial and mycorrhizae inoculants for those species that require them for successful establishment and survival.

IV. References

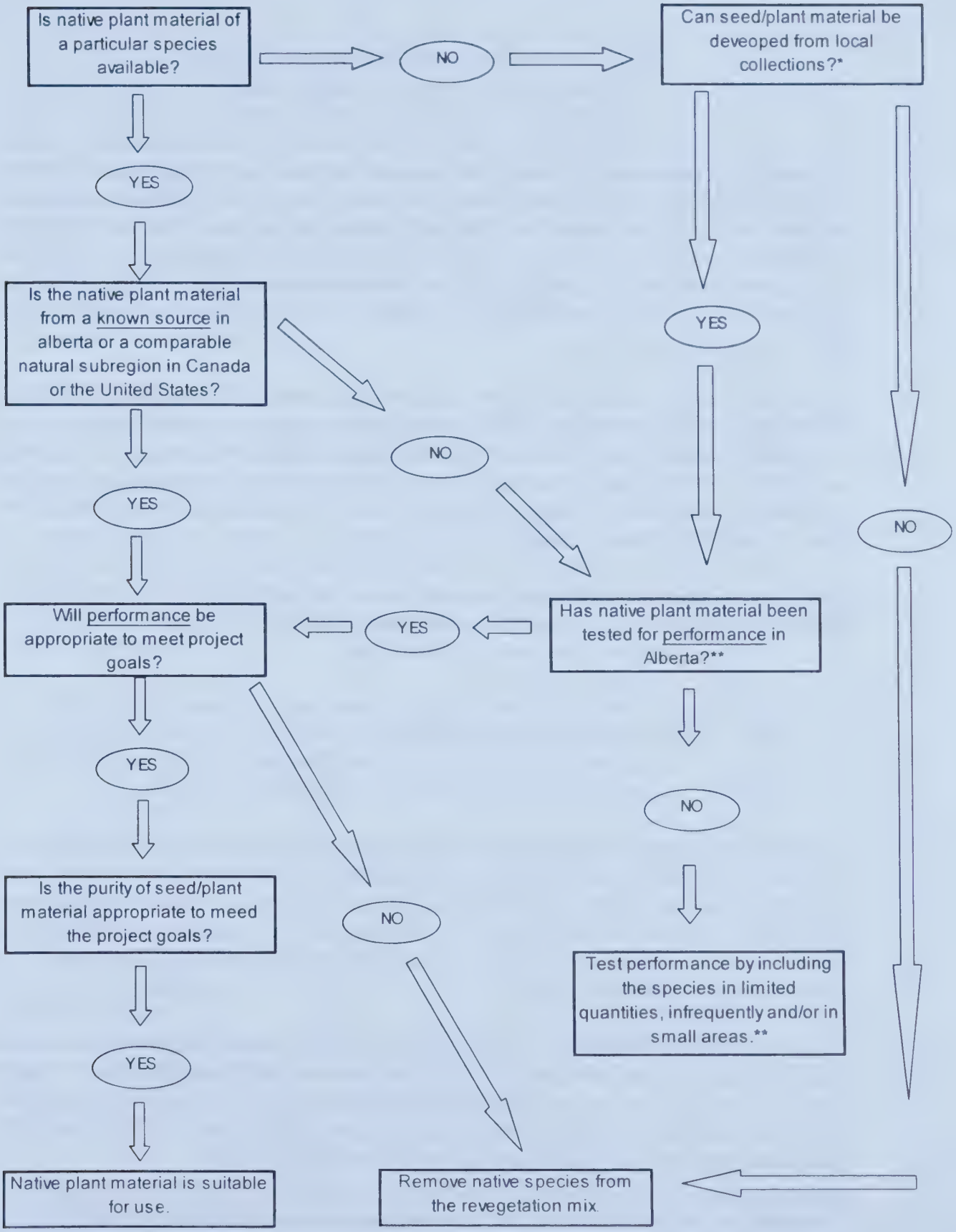
Alberta Energy and Utilities Board. 1996. Petroleum Activity on Native Prairie: Guidelines for Surface Disturbances. 10 pages.

Alberta Agriculture Food and Rural Development, Public Lands Division. 1996. Weed content in native seed used for revegetation of natural landscapes. IND 96-1. 3 pages.

Alberta Agriculture Food and Rural Development and Alberta Environment. 1999. Draft Native Plant Revegetation Guidelines for Alberta. 55 pages.

Gerling, H.S., M.G. Willoughby, A. Schoepf, K.E. Tannas and C.A. Tannas. 1996. A Guide to Using Native Plants on Disturbed Lands. Alberta Agriculture, Food and Rural Development and Alberta Environmental Protection. 247 pages.

Figure 1. Decision-Making Chart: Sourcing Native Plant Material


Is native plant material of a particular species available?
NO
Can seed/plant material be deveoped from local collections?*
YES
YES
Is the native plant material from a known source in alberta or a comparable natural subregion in Canada or the United States?
NO
NO
YES
YES
Will performance be appropriate to meet project goals?
YES
Has native plant material been tested for performance in Alberta?**
YES
NO
Is the purity of seed/plant material appropriate to meed the project goals?
NO
Test performance by including the species in limited quantities, infrequently and/or in small areas.**
YES
Native plant material is suitable for use.
Remove native species from the revegetation mix.

NOTES

* prior to removing species from the revegetation mix, multiple attempts to secure alternative sources is recommended

** records of procedures and results should be maintained and made generally available.

Alberta Orphan Well Program*

Pat Foo, Alberta Energy and Utilities Board

The Alberta Orphan Well Program is part of a joint industry-government initiative which is unique to the province of Alberta. The Program is funded by what is commonly known by the oil and gas industry as the Orphan Well Fund. The Oil and Gas Conservation Act was amended in 1994 to create the fund which started out as a restricted fund to pay for the abandonment of orphan wells only. In 1997, approval was given to expand the activities of the fund to include pipeline abandonments, facility decommissioning, remediation and reclamation. With this expansion, the funding for the Program is now referred to as the Orphan Fund.

The Orphan Fund is funded entirely by the oil and gas industry and is administered by the Alberta Energy and Utilities Board. The main source of revenue for the Orphan Fund is a levy paid by industry based on the number of inactive wells each company holds at the end of the calendar year. This levy is set annually to fund the clean up activities conducted by the Fund. A second source of revenue is the first time well licensee fee. The third revenue source is interest.

The Alberta Orphan Well Program operates under the direction of the Fund Advisory Committee which is composed of representatives from the following stakeholders:

EUB	Alberta Energy and Utilities Board
AENV	Alberta Environment
AFRD	Alberta Department of Agriculture Food and Rural Development
AE	Alberta Department of Energy
CAPP	Canadian Association of Petroleum Producers
SEPAC	Small Explorers and Producers Association of Canada

The FAC established a subcommittee, the Peer Review Group, which is composed of representatives from CAPP, SEPAC, EUB and AEP. The Peer Review Group meet monthly to look at requests from EUB and AEP to deem wells, pipelines, facilities and well sites as orphans for the purpose of abandonment or reclamation. Once deemed, authorization is given to the Alberta Orphan Well Program for expenditures out of the Fund to conduct cleanup activities.

In the fiscal year of 1998/99, approximately $4.3 million dollars was collected in revenue and $4.8 million dollars was spent on well abandonments, pipeline abandonments, facility decommissioning, site reclamation and administration. This is the first year that a significant amount of work was conducted on expanded activities. Approximately $2.7 million dollars was spent specifically on site reclamation activities.

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Qualified Reclamation Practitioners in Alberta*

David Lloyd, P.Ag., Alberta Environment

Currently, no specific educational training or experience is required for individuals to practice reclamation in Alberta. This means that individuals with a wide range of training and experience are working in the reclamation field. Various industries have advised that the success of reclamation programs meeting specified criteria is variable. It is generally believed that a base set of practitioner qualifications will help to enhance reclamation success in the field and better ensure compliance with reclamation legislation in the province of Alberta (EBA, 1998).

A Alberta committee made up of members from five different professional bodies has been working for 3 years to develop certification criteria for reclamation practitioners and to propose an administration system that would run the certification program. The Alberta Institute of Agrologists initiated the review by asking David Lloyd to form a working team made up of members from other professional bodies. The Engineers, Foresters, Biologists, Agologists, Alberta Environment (initially) and the Canadian Land Reclamation Association subsequently formed a working group to develop a draft certification process and criteria for individuals practicing reclamation in Alberta. The working group developed a vision, mission and a guiding set of "principles" to focus their work. These were:

VISION:

The establishment of qualifications for land reclamation practitioners to ensure high standards of land reclamation practice.

MISSION:

To oversee the development and design of basic qualifications for land reclamation practitioners in Alberta and to recommend an operating framework for use of these qualifications

GUIDING PRINCIPLES

Diversity of qualification
National mobility
Consensus decision in design
Satisfy affected stakeholders
Multidiscipline inclusion – experience and education
Flexibility
Voluntary process
Explicit standards

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To assist the working group, a consulting firm, EBA Engineering, was hired in 1997 to suggest a minimum education and training background for individuals working in reclamation. The consultant was asked to propose an administrative system that would oversee and run the certification process. EBA submitted a report in 1998 recommending a base set of educational and experiential criteria which any individual should have when working in the reclamation field. EBA also conducted a telephone survey of various parties to determine general response to certification. There was a significant amount of support for certification from the 74 respondents of the survey. There were also many reservations about how certification cold be meaningfully and fairly implemented, and appropriately address the wide range of knowledge, skills, training and experience required in the diverse conditions in Alberta (EBA, 1998).

Some survey results were:

73% surveyed believed some individuals were not able to carry out reclamation work to adequate standards
92% felt voluntary minimal qualifications would be beneficial for people doing formal site assessments; 82% for people doing on-site supervision; 93% for government inspections and 66% for reclamation management.
53% were in favour of at least a 2 year college education
46% favoured a 1-2 years work experience
35% favoured > 2 years education
68% favoured a practicum

The consultant suggested 3 possible administrative processes to run a certification program. The working group followed up EBA's report by pursuing one of these options. The Canadian Council Human Resources in the Environment Industry (CCHREI) was approached to determine if they would administer a certification program for land reclamation practitioners. Subsequent to the meeting with CCHREI., the working group decided that a "formal" certification program was not in the best interests of affected parties. The working proposed that a qualification criteria for land reclamation practitioners would be "voluntarily endorsed" by each of the associations/professions as a definition of what experience/training an individual needs to practice land reclamation. If an industry desires an experienced, trained individual for reclamation work, then the professional/technical organizations may indicate to that industry the qualifications they have endorsed for individuals who practice in this area. At this time it is clearly intended that there be NO formal certification requirement established for qualified land reclamation practitioners. The original working group has tabled a draft certification criteria for discussion purposes to their respective organizations. The draft criteria will be used as a template for further work. A summary of the proposed criteria is listed in Tables 1&2 below.

TABLE I - SUGGESTED TECHNICAL EDUCATION (EBA, 1998)

Subject Requirements	Rationale
Terrain Science • introduction to landforms • introduction to surficial deposits	• enhance understanding of landscape/soil relationships • understanding of erosion potential • recontouring landscapes and reestablishment of natural drainage patterns in reclamation
Soil Science • introduction to soil properties (physical, chemical, biological) • introduction to soil quality/capability? • introduction to soil classification	• ability to understand/assess predisturbance or adjacent soil properties • understand/assess soil quality and equivalent capability • understand soil/landscape relationships ability to comment on appropriate amendments and protection measures • understanding of soil conditions to assist in selecting suitable revegetation program
Plant Science • introduction to plant growth • introductory ecology – forest and grassland communities • introductory range management • introduction to weed identification and control • introduction to revegetation	• understand and create conditions favourable for plant growth and therefore develop suitable revegetation programs • selection of appropriate species, seeding procedures, and promotion of conditions for reestablishment of native vegetation • ability to assess success of revegetation program and relate to pre-disturbance condition or adjacent land base • weed control and adaptive management as required
Reclamation • introduction to equipment (farming equipment, construction and reclamation equipment etc.) • introduction to processes (eg. Seeding, farming practices erosion control, etc.) • soil amendments • criteria • understanding construction and operation practices	• necessary knowledge to develop and/or supervise a reclamation program **question – does this need to be a course or something that is acquired via experience – many practitioners would not be qualified in this area without specifically going through a reclamation program at school but they may have all the good tools to become excellent practitioners
Regulatory Regime • AEPEA • Relevant guidelines	• practitioners must understand the requirements to ensure final product is suitable ** same comment as above – this is easily something to be acquired in the field – regulations and requirements change so courses at school would be beneficial but not essential
Aerial photography interpretation Map Reading	• skills are essential to the practical aspect of working in the industry
Recommended Subjects: • Ecology • Wildlife • agriculture (various courses) • chemistry	

TABLE II - SUGGESTED EXPERIENCE (EBA, 1998)

Experience/Skill	Rationale
Terrain and Soil • assess soil properties in field (eg. Texture, structure, etc.) • relate changes in undisturbed soil to landscape position • ID soil horizons, ID oil to subgroup level • Recognize disturbed soil and effect on soil properties and soil quality • Recognize and assess problem soil properties and relate to natural conditions, construction activities and reclamation needs • Ability to determine corrective measures • Recognize presence of contaminants, sample appropriately • ID and assess site drainage and soil moisture problems • Ability to assess appropriateness of soil amendments and quality of organic material	• these skills are required to correctly assess pre construction, pre reclamation and post reclamation conditions; develop a reclamation plan, supervise reclamation, etc.
Vegetation • assess vegetation growth and vigour for annual crops, forage and natives • ID species determine seed appropriate for revegetation –based on site conditions • ID weeds and determine appropriate control measures • Assess revegetation success and trouble shoot to address problems	• these skills are required to correctly assess pre construction, pre reclamation and post reclamation conditions; develop a reclamation plan, supervise reclamation, etc.
Reclamation • familiarity with construction, reclamation and revegetation procedures (eg. Stripping, decompaction, seedbed prep.) • familiarity with equipment, its effect on soil, its appropriateness under site and weather conditions • costing of reclamation programs • recognize contaminants • determine appropriate landscape for drainage, erosion control, etc. • familiar with farming systems	• these skills are required to correctly assess pre construction, pre reclamation and post reclamation conditions; develop a reclamation plan, supervise reclamation, etc
Regulatory Regime • assess sites to meet criteria	• ensure compliance

The working group has determined that further consultation is needed with other professional bodies and with the consulting industry. The original working group has proposed that the existing committee be expanded to include new working members. The new members will consist of at least the following:

- 4 members from the consulting industry
- Forest Technologists
- Engineering Technologists
- Landscape Architects
- Members from the original working group organizations (Agrologists, Foresters, Biologists, CLRA and Engineers).

Meetings are ongoing with individuals from each of the above groups. The expanded working group will work toward developing a more complete set of educational/experience guidelines for reclamation practitioners. A reclamation certification criteria draft document, endorsed by the working group, will then be submitted to each organization for review and comment.. Each organization will then decide how they want to pursue any form of specialization/cert5ification process.

References

1. EBA, Investigation into the Development of Certification For Land Reclamation Practitioners in Alberta. A Report Submitted to the Qualified Reclamation Land Reclamation Practitioners Working Group. Edmonton, Alberta, April, 1998.

Remediation / Waste Disposal

Bioremedial Options*

Dr. Al Jobson, Stantec Consulting Ltd.

Site contamination can involve either organic or inorganic fugitive compound(s) or element(s). This brief review will concentrate on possible bioremedial options for organic pollutants in soil or groundwater, or both.

Certain contaminated sites afford the opportunity, based upon an environmental impact assessment or an environmental risk assessment, to allow "natural processes" to take their course over an extended time period. This is referred to as natural attenuation. This process is primarily biological in nature, but can also involve physical parameters as well, including solution, dilution, evaporation, precipitation, complexing processes and adsorption. Thinking of "non-action" as a remedial option depends upon the nature of the contaminant(s), the microbial population surviving/existing/metabolizing within the contaminated zone, the degree of contamination (existence of free product) and whether the contamination impacts only the vadose zone or both the vadose and the saturated zones.

Undertaking an active in situ bioremedial treatment program can involve a number of options and varying levels of complexity. In its simplest form it might involve the injection of nutrients such as ammonium, nitrate, phosphate, or micronutrients at groundwater depths to stimulate the growth of microorganisms already present in this environment. In some cases air is injected at groundwater depths, or within the vadose (unsaturated) zone in an attempt to provide a more aerobic environment for the existing microbial population. In other cases alternate electron acceptors such as nitrate are injected within the contaminated zone to allow specific microbial groups (denitrifiers) to metabolize contaminants in a manner similar to aerobic organisms without the need for molecular oxygen to be present.

Another technique gaining acceptance is the injection of oxygen releasing compounds at contaminant depths. These compounds gradually liberate molecular oxygen into this environment over several weeks or months and thereby stimulate aerobic microbial growth, which will hopefully be at the expense of the in situ contaminant compound(s).

Bioventing refers to the injection of air at varying depths within a contaminated soil profile in order to cause volatile contaminant compounds to be carried to the soil surface and be "vented" to the atmosphere. In some cases the near surface soil is fertilized to

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stimulate microbial activity which will, in turn, adapt to growing on the stream of volatile contaminants passing through it. This system is sometimes referred to as a biofilter.

A more complex in situ biotreatment option employs a system of harvesting groundwater and soil vapor from a contaminated soil region, passing this material through a fermentation process at the surface and then re-introducing the fermentation liquid back into the contaminated soil zone, usually up-gradient from the region where the contaminated groundwater was originally harvested. When successful, this system allows the captured groundwater to be decontaminated, while at the same time introducing an active, induced and increasingly large microbial population back into the zone of contamination. Such technologies have been given various functional names, including bioslurping and biosparging.

If it is necessary to excavate and treat contaminated soils and groundwaters ex situ, various techniques are again available. Groundwater can be pumped, biotreated in a reactor or a fermenter and then released directly into the environment, or to a sanitary sewer system. Groundwater and often large quantities of contaminant materials can be captured for ex situ biotreatment by means of a high vacuum dual phase extraction system. Although relatively expensive to operate, these systems are capable of harvesting large volumes of contaminated groundwater as well as free contaminant material. In some cases it is a cost-effective option to biologically treat the contaminated co-produced water.

Excavated contaminated soil can be landspread, landfarmed, biopiled, or bioreacted in a construced bioreactor or a slurry reactor. Microbial treatment via these techniques has proven successful for a wide variety of contaminant organic compounds.

Phytoremediation is an emerging and increasingly recognized bioremedial option. It includes the use of phreatophytic plants to consume large volumes of groundwater, thus preventing net groundwater flow further downgradient. This, in turn, can help to prevent further downgradient movement of contaminant plumes. Phytoremediation also describes the essential role aquatic plants play in the bioremedial capability of constructed wetlands. Phytoremediation also refers to the use of plants (and their root systems) to act as primary hosts for microbial populations which, in turn, have the ability to catabolize contaminant organic compounds. It is theorized that as plant roots push forward in their soil environment the associated microbial population will remove soil organic contaminants which might otherwise prove toxic to these plants. Much still remains to be learned regarding this possible symbiotic activity in circumstances of severe soil contamination.

In-situ Biodegradation of Ethanolamine in Low Permeability Soils*

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Abstract

Ethanolamine is commonly used in gas sweetening operations and in some cases, has been found in the soil and groundwater at gas plants. Ethanolamine is reported to be amenable to biodegradation. At certain sites, however, low permeability soils hamper the ability to provide microbial consortia with the necessary nutrients for metabolism. A research program was initiated at a former Edmonton area gas plant site to demonstrate *in-situ* site remediation techniques. A horizontal well was drilled at a depth of 4m below ground surface and hydraulically fractured to increase the permeability of the glacial till soils. Fractures were initiated in 12 locations with a water-based slurry. A sand propant was used to prevent their subsequent closure. Phosphoric acid was added to the well to provide a source of orthophosphate to stimulate the growth of the native bacteria. Well completion failed when the slotted PVC piping parted in tension. A second horizontal well was drilled adjacent to the first and was completed using a pre-tensioned steel cable to prevent the PVC from failing. The horizontal well and fracture network were then

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used as part of a bioventing demonstration. A network of monitoring wells was installed along the horizontal wells to test the pneumatic connection with the fracture network and to monitor bacterial respiration. Oxygen required for the aerobic degradation of the amines and glycols was provided from atmospheric air in two ways; first in a positive pressure mode employing a 1 HP blower and then by vacuum extraction using a 5 HP liquid ring pump. Field results demonstrated oxygen depletion and carbon dioxide production which indicates the presence of biological activity. Pneumatic connection between the monitoring wells and fracture network was relatively poor, possibly due to the invasion of water into the network. While preliminary site characterization did not indicate the presence of shallow groundwater, water-levels in the monitoring wells confirmed groundwater presence. Ethanolamine levels in groundwater extracted from the monitoring wells showed an overall decline in concentration while ammonia levels did not change. Ammonia is a breakdown product of amines and provides further indication of microbial degradation. However, the concentration of ammonia in the groundwater may be sufficiently high to exert a toxic influence on the soil bacteria, preventing additional degradation.

1.0 Introduction

1.1 Overview of the Research Objectives

In order to demonstrate and evaluate the effectiveness of *in-situ* technologies for remediation in low permeability media, a research program was established at a decommissioned natural gas plant near Edmonton, Alberta. The three research objectives at the field site were to evaluate the effectiveness of: drilling a shallow horizontal well, using the horizontal well to induce hydraulic fractures to increase the bulk permeability of the soils at the site, and establishing a pilot bioventing program using the induced fracture network to enhance the biodegradation of ethanolamine-impacted soil. The results from the research program will be presented and discussed after a brief introduction to the issues and the field site.

1.2 *In-Situ* Remediation and Low Permeability Soils

In-situ technologies are designed to remediate impacted soils and groundwater without the need for costly excavation and disposal. Most *in-situ* methods require access to the impacted region via the permeability of the porous media. Thus a limitation of the majority of *in-situ* techniques for the remediation of contaminated soil and groundwater is low permeability porous media. In Canada, low permeability surficial soils such as glacial tills are very common and while they vary significantly in composition, they have relatively low permeabilities (10^{-9} to 10^{-15} cm^2). As a consequence, there are many sites in Canada, which are not amenable to conventional *in-situ* remediation. One technique to improve access to impermeable soils is by inducing fractures within the porous media to

serve as conduits for fluid transfer. After increasing the permeability with fractures, it is possible to apply a variety of *in-situ* remediation strategies.

1.3 Hydraulic Fracturing and Horizontal Wells

Environmental fracturing may be accomplished pneumatically or hydraulically by pumping a fluid into a well at a rate and pressure high enough to overcome the confining stress of the geologic material, resulting in a fracture that propagates into the formation (Frank and Barkley, 1995). To prevent the fractures from resealing because of overburden stress, a granular propant (e.g. coarse sand) may be hydraulically pumped into the fracture. The propant filled fractures are significantly more permeable than the formation and may then be used to deliver or withdraw fluids or other constituents from the subsurface. In this way, a much larger volume of impacted soil and groundwater may be targeted in a more reasonable time-frame. In some cases, it is possible that induced fractures will intersect natural porous media fractures, enabling access to an even larger volume of the subsurface in an interconnected fracture network.

Fracturing may be accomplished from either vertical or horizontal wells. While vertical wells are less expensive, horizontal wells can target regions inaccessible to vertical wells (e.g. under buildings or operational facilities).

1.4 Sour Gas Sweetening Operations

Produced natural gas often contains considerable quantities of acid gases such as hydrogen sulfide (H_2S) and carbon dioxide. Gas with significant H_2S concentration is referred to as sour gas. Because of its toxicity, it must be treated to remove the H_2S. Carbon dioxide must also be removed before the gas is transported to the consumer to reduce corrosion problems. One common method for the removal of carbon dioxide and H_2S is to "sweeten" natural gas using a process involving alkanolamines. Alkanolamines are organic derivatives of ammonia (NH_3) and are effective at removing acid gases (CO_2, H_2S) from natural gas because of their basic characteristics. Common types of alkanolamines used in gas sweetening include ethanolamine (also called monoethanolamine, MEA), diethanolamine (DEA), methyldiethylamine(MDEA), and diisopropanolamine (DIPA) (CAPP, 1996). There are reported to be more than 90 gas sweetening operations in Canada and an additional 394 in the United States (Sorensen *et al.*, 1999). Because of the widespread use of alkanolamines for sweetening natural gas, soils and groundwater at some gas plants have been impacted and require remediation.

1.5 Amine properties and Biodegradation

Alkanolamines like such as MEA, DEA, and TEA are high pH organic liquids which are completely miscible with water. Table 1 provides some of the physical properties of MEA. Because MEA is miscible with water in all proportions, it is free to flow with

groundwater. However, Sorensen *et al.* (1997) report distribution coefficients (K_d) ranging from 2.21 to 4.91 in the pH range of 6.5-8.5. Clear trends based on pH or concentration were difficult to interpret, but K_d values in this region indicate significant sorption to sediments and therefore limited mobility. One caveat however, is that at pH values above the pK_a of MEA (9.4), MEA would be unprotonated and would likely have increased mobility (Sorensen *et al.*, 1997).

Table 1: General Physical and Chemical Properties of MEA [1,2]

Chemical Formula:	C_2H_7NO	Chemical Structure:	$NH_2–CH_2–CH_2–OH$
Molecular Weight:	61.08	Physical State @ STP:	Liquid
Boiling Point:	170.8 °C	Specific Gravity:	1.0
Freezing Point:	10.5 °C	Odor/Appearance:	Ammoniacal/colorless
Flash Point:	94 °C	Aqueous Solubility:	Completely miscible
Vapor Pressure:	< 0.13 kPa @ 24 °C	Viscosity:	24 centistokes @ 38 °C
Vapor Density:	2.11	pH of 25% aq. soln.:	12.1

[1] (IOR, 1994)
[2] (Budavari, 1996)

There are numerous reports in the literature that amines are biodegradable in both aerobic and anaerobic modes (e.g. Scarlett and Turner, 1976; Williams and Callely, 1982; Knapp *et al.*, 1996; CAPP, 1996; Sorensen *et al.*, 1997). In some cases, amines may provide both a carbon source and a nitrogen source for degradation. While there may be more than one chemical pathway governing alkanolamine degradation depending on the microorganisms present and site conditions, research indicates that both aerobic and anaerobic degradation can mineralize amines such as DEA and MEA to water, carbon dioxide, and ammonia. Figure 1 provides a proposed breakdown pathway for MEA (after Knapp *et al.*, 1996; Williams and Callely, 1982). The MEA is degraded to acetaldehyde with the evolution of ammonia. The acetaldehyde reacts in turn to form either ethanol or acetic acid which are easily mineralized in the soil to water and carbon dioxide. The ammonia, however, may accumulate or may by consumed by nitrifying/denitrifying bacteria to form nitrite, nitrate, and ultimately nitrogen gas. Ammonia speciation is dependent on pH and for water around 10°C-20°C, will be distributed as NH_4^+ at pH values of 8 or less, as a mixture of NH_3 and NH_4^+ at pH values between 8 and 11.5, and as NH_3 at a pH above 11.5. (Viessman and Hammer, 1985). This may play an important role in amine degradation because alkanolamines are basic compounds and NH_3 is significantly more toxic to organisms than the NH_4^+ species (Vershueren, 1983). Additionally, ammonia accumulation without nitrification may inhibit the degradation of amines.

2.0 Site Characterization and Program Methodologies

2.1 Site Characterization

The field site chosen to conduct research is at the location of a decommissioned gas plant. The plant was used to sweeten gas produced from a sour gas well on-site. The site is near the top of a hill with natural drainage boundaries on all sides. The boundaries include deep drainage gullies immediately to the east and west of the site which curve and join to the north of the site. To the south there is a fairly steep drop leading to a lake approximately 500m away. Gas production and treatment operations ceased in 1993 and all infrastructure was removed from the site except for one small building used for storage. The natural gas treatment operations at the site introduced amines and glycols to the surface soils on a raised fill pad at the north end of the site. These compounds migrated into the soil and are found to be within the top 4m below ground surface (bgs). The soils within this zone include a surface fill layer (0.5-1m) followed by a sandy silt with sand lenses grading to a cohesive and dense clay till approximately 3.5m bgs. During initial site characterization, augered test holes did not encounter flowing water. However, after implementation of the bioventing program, seasonal water was found to enter most monitoring wells indicating a fluctuating water table several meters bgs.

Figure 2 provides a plan-view schematic of the portion of the site relevant to this research program. The horizontal well is illustrated and trends from the northwest to the southeast at a depth of approximately 4m becoming shallower prior to exiting the ground at both ends. Monitoring nests (97-1 to 97-13) were placed to interpret the effectiveness of the horizontal well, the fractured network, and the bioventing pilot demonstration. Each of the 13 nests has two 5 cm PVC piezometers. The screened portions (0.75m screened intervals) are at approximately 2m bgs (designated as 97-1A, 97-2A, etc.) and approximately 4m bgs (designated as 97-1B, 97-2B, etc.). All the piezometer nests are placed within the screened interval of the horizontal well. The nests 97-1, 97-2, and 97-3 were intended to represent wells outside the influence of the fracture network. The induced hydraulic fractures are located in twelve 2m intervals from 4m southeast of piezometer 97-4 to approximately 4m northwest of 97-11. Figure 3 provides an illustration in a sectional view along the horizontal well. It shows the fractured region, the location of the monitoring wells and the overall concept of bioventing by either injecting air with a blower or removing it by vacuum extraction.

Figure 2 shows groundwater elevations and flow direction for high watertable conditions during the 1998 field season. The pattern of flow is radially outward from an area upgradient from the horizontal well where an earlier unrelated study had been implemented. The pattern of flow and the boundary conditions imposed by the drainage gullies and the hill suggest that the water is entering the ground predominantly through infiltration. The water present at the site may be perched on the dense clay tills approximately 3.5m-4m bgs.

Initial chemical characterization identified amines (principally MEA) and glycols (principally ethylene glycol and triethyleneglycol) emanating from the treatment pad area which was located in the area northeast of the horizontal well in Figure 2. Only the amines will be considered here. Soil sampling indicated that the MEA had migrated to the southwest. The soil analyses in this relatively small region indicated MEA levels ranging from 4 to 16000 mg/Kg, ammonia levels from 25 mg/kg to 1000 mg/kg, and pH values varying between 7.2 and 9.6. Elevated iron and manganese levels were also recorded. The soil analyses were used to choose the location for the field research program.

2.2 Field Program Chronology

The soil sampling for the field program was conducted in July of 1997 by Komex International Ltd. The initial horizontal drilling and hydraulic fracture program was completed in September 1997. Drilling was contracted to RamCor Directional Drilling Ltd., and the fracture network was installed by Frac Rite Environmental Ltd. using subcontractor Eco Scan Inc. for prediction of fracture propagation. Because of completion difficulties (discussion to follow), a second horizontal well was drilled and completed in October, 1997, followed by installation of the monitoring wells shown in Figure 2. The initial bioventing program was conducted from November 1997, to April 1998, but was hindered by excess water at the site. In April 1998, a bioventing program using vacuum de-watering was used to aerate the subsurface. After de-watering was complete, bioventing by positive pressure air injection continued until the end of the field season in September 1998. In October 1998, an aquifer test was conducted to aid in the interpretation of the groundwater issue. Extensive water sampling programs were conducted in April and September 1998, to evaluate the effectiveness of the bioventing program.

2.3 Chemical Analysis

Soil and water analyses were conducted using standard commercial laboratory methodologies by Philips Analytical Services in Burnaby, BC. Amine analyses were conducted by ion chromatography (IC). It became apparent, however, that the standard IC method was unable to properly separate ammonia and MEA when both are at high concentrations. To solve this problem, CAPP (1996) recommended the use of a Dionex C-14 column using 18-crown-6 ether added to the eluent to increase the separation between the ammonia and MEA peaks. However, the 18-crown-6 ether was found to be detrimental to the system hardware and therefore Dionex has developed an alternative column (C-15) which incorporates the 18-crown-6 ether directly into the column. This column separates the ammonia and MEA peaks well.

3.0 Results and Discussion

3.1 Horizontal Well Installation and Induced Hydraulic Fractures

The horizontal well (5 inch ID) was drilled along a 55m section of the site at a depth of 4m bgs as indicated in Figures 2 and 3. The direction and depth of the well was successfully monitored from the surface by RamCor. Note that this well, unlike some horizontal wells had an entry and exit hole. After drilling the hole from the west side of the site to the east side, Frac Rite Inc. attached their frac tool to the drill string and it was pulled back into the hole to initiate twelve fractures (F1 - F12 in Figure 3). The fractures were spaced two meters apart except for F11 and F12, which were 3m apart. Frac Rite injected a total of 3650 Kg of 20-40 mesh sand (propant) using 5200 Liters of fluid slurry to create and maintain the fractures. Fracture initiation pressures ranged from 0.5 to 1.3 MPa. In several cases (F3, F4, and F11), fracture fluid vented to the surface through the bentonite-grouted test holes used by Komex for soil sampling. Based on their operations, Frac Rite recommends that for future shallow environmental fracturing, test holes should be kept at least 5m away from the fracture zone. This may be unreasonable given the necessity for site characterization. Where necessary, test holes should be grouted with cement rather than bentonite prior to fracturing to prevent extrusion of the bentonite grout and loss of fracture fluid and pressure.

Eco-Scan Inc. was subcontracted by Frac-Rite to predict the orientation of the induced hydraulic fractures. Tiltmeters were placed in an array on the ground surface and were used to measure the ground displacement after each fracture was initiated. Computer modeling by Eco Scan Inc. predicted the magnitude and orientation of each fracture. The computer model assumes that the ground displacement is caused by the addition of a single planar fracture to the subsurface. This precludes the possibility of branched fractures. In general, the predicted fractures were found to propagate sub-horizontal (within 30° from horizontal) from the well with thickness ranging between 1-18mm. Figure 4 shows the predicted fractures superimposed on one another and placed on the site schematic. It is evident that the fracture geometry is variable and it is likely that fractures in the eastern portion may have joined to form a single, larger fracture. Predictions for fracture geometry made on a vertical test-well fractured at the site and later excavated by the University of Calgary (Alfaro and Wong, 1998) were in general agreement with the observed fracture orientations.

After the initiation of the fractures, and prior to well completion, 625 Kg of dissolved phosphate amendment was pumped into the horizontal well as a nutrient to stimulate microbial activity. Because of time constraints, it was necessary to leave the drilled and fractured well open overnight prior to completion. The next day, the drill string was re-advanced into the well. A 15 cm OD backreamer was attached to the drill string followed by the PVC well casing and a tremmie pipe to emplace a sand pack. Unfortunately, the slotted PVC pipe broke while it was being pulled into the horizontal drill hole from the east end, leaving a 17m length of PVC in the subsurface at the east end of the well.

According to the drillers, the pull back force increased substantially just prior to the break. It is interpreted that some kind of hole collapse or partial cave-in occurred, binding the PVC pipe in the drill hole. The pipe then failed in tension at the screen slots. Rather than attempt to re-drill the hole, a second well was drilled and completed at a later date approximately 1m south of the first well. It was anticipated that the well would intersect the fractures from the original well. During completion, a pre-tensioned steel cable was placed inside the PVC casing to prevent it from parting in tension. No sandpack was installed. For future installation using a non-metal casing, it is recommended that a pretensioned cable be used during installation. It is also recommended that completion of the hole be conducted immediately after the horizontal drilling and fracturing operation.

3.2 Pneumatic Connectivity of the Fracture Network

In order to test the pneumatic connectivity and increased permeability of the subsurface due to hydraulic fracturing, two methods of testing were undertaken. The first measured the pressures or vacuum at each of the monitoring points when pressure or suction was applied to the horizontal well or to individual monitoring wells in the system. The second method involved measuring the hydraulic conductivity of the subsurface.

Prior to initiating the first phase of bioventing, a vacuum was applied to the horizontal well, and in turn, to other monitoring wells to assess the pneumatic connectivity. Following this, air pressures were measured routinely in the monitoring points during the initial phase of bioventing (air injection) until the spring of 1998. Because of water infiltration, however, air connectivity in the fractures was difficult to measure. Throughout the testing matrix however, all wells except 97-1, 97-2, and 97-3 showed some response to pressures/vacuum either applied to the horizontal well or to other monitoring wells. The horizontal well had poor pneumatic connection with all the wells except 97-5b, which demonstrated a good connection with the well. This suggests that the second horizontal well did not intersect very many of the hydraulic fractures initiated in the first well or that water interfered with the connectivity.

Water levels rose ubiquitously across the site in the spring of 1998 and in some cases covered the well screens completely. Initial site characterization did not anticipate the presence of so much groundwater. The water interfered with the first phase of bioventing operations and prevented a thorough assessment of pneumatic connectivity. However, the groundwater provided an opportunity to monitor chemical composition spatially with time and a means to assess the permeability of the fracture network hydraulically. The second phase of bioventing was conducted by de-watering the site using a 5 HP liquid ring vacuum pump to withdraw water from the horizontal well and from well 97-8b. At the lowest water levels during de-watering (June 1998) all the monitoring points except for those wells outside of the fracture network (97-1, 97-2, and 97-3) showed a vacuum

connection (-0.1 to <-25 KPa). These data indicate the increased connectivity in the fracture zone.

3.3 Hydraulic Conductivity

The high water levels at the site allowed an assessment of the increased hydraulic conductivity (and thus permeability) caused by the fracture network. The hydraulic assessment of permeability included: slug tests conducted on selected monitoring wells before de-watering, the water recovery curves after de-watering, and an aquifer test and additional slug tests conducted after the water levels had recovered. The analysis of the data was conducted by Komex using a variety of standard groundwater analytical techniques.

Table 2 provides a summary of the mean hydraulic conductivity results for three of the different methods used. The results are averages of a number of monitoring wells used in each of the different test methods. The aquifer test and dewatering test are long term tests (several weeks to several months respectively) and target a much larger volume of porous media than the individual slug tests. Thus the aquifer test and especially the de-watering test should give a fair representation of the bulk site hydraulic conductivity. The best data for this bulk value are the recovery tests given that they are the least impacted by local heterogeneity imparted by the fractures. The slug tests provide a more local measure of hydraulic conductivity and may indicate whether or not the fractures have contributed to an increase in conductivity.

Within the fractured area, the mean hydraulic conductivity of the slug tests for the wells measured (4B, 8A, 8B, 9B, 10B, 11B) is over twenty times the value of the aquifer test recovery mean and 45 times the de-watering test mean. This indicates that local permeability is increased in the porous media in the proximity of the fractured zone. However, it must be noted that the unfractured area slug tests along the horizontal well also gave roughly the same value as the fractured area, begging the question of whether or not the fractures really changed the permeability. To respond to this, it was only possible to conduct 2 shallow piezometer slug tests (97-1 and 97-3) in this area because the rest of the wells did not supply enough water. The deeper piezometers measured in an unfractured area upgradient were less permeable than the fractured zone wells. Additionally, only some of the wells within the fracture zone are likely to intersect fractures. The rest will have lower permeability.

Table 2: Log normal mean hydraulic conductivity results (m/s)

Media Type	Aquifer Test		De-watering Recovery	Single Well (slug) Test
	drawdown	recovery		
Unfractured Area	N/A	N/A		$6.5 \times 10^{-}$

Unfractured Area (upgradient)	N/A	N/A		$3.0x10^{-8}$
Fractured Area	$9.0x10^{-8}$	$2.9x10^{-8}$	$1.5x10^{-8}$	$7.0x10^{-7}$

To provide a different perspective, Figure 5 shows the scatter of all the measured values split into three categories. The de-watering and aquifer tests are bulked into one category called aquifer test and the others are self-explanatory. This scatter plot more easily demonstrates that the hydraulic conductivity values within the fractured region are higher than those in the unfractured region. The aquifer test values further demonstrate that the fracturing program increases permeability locally compared to background values.

3.4 Bioventing Pilot

The bioventing pilot was initially designed to stimulate the aerobic degradation of amines in the induced fracture network via aeration or suction through the horizontal well. As discussed, the presence of unexpected quantities of water and the difficulties encountered with completion of the horizontal well hampered the proposed bioventing program. Over the course of the research program, the initial design was modified to enable the study to continue. The initial bioventing program operated from November 1997 to April 1998 and involved positive pressure injection of air into the horizontal well using a 1 HP blower. When the water levels rose in the spring of 1998, the de-watering bioventing program was established. While the water hindered the initial bioventing, it provided an analytical means to test the effectiveness of the de-watering bioventing because water samples are more easily taken than soil samples. Thus a suite of samples was taken before and after the bioventing. One point that must be considered, however, is that the water may simply dissolve and dilute the contaminated region and not actually reduce amine concentrations due to bio-degradation. While this remains a critical issue, there are several lines of evidence that suggest that bioremediation occurred at the site. These will be explored.

3.4.1 Carbon Dioxide Evolution and Oxygen Depletion

The initial plans to monitor the progress of remediation were to measure the gas composition at the monitoring wells. As with most aerobic processes, carbon dioxide is produced and oxygen is consumed during the aerobic metabolism of MEA, Throughout the field program oxygen and carbon dioxide were measured using a Nova Instruments Analyzer. Normal atmospheric levels of O_2 and CO_2 are 20.9% and 0.03% respectively. Field results demonstrate that for many of the wells in the fractured region, there is a significant reduction in O_2 and a corresponding increase in CO_2. Some wells in the fractured zone had levels of O_2 below 5% and CO_2 levels as high as 13% of the gas stream. P97-1 and P97-3 on the other hand generally did not show much deviation from atmospheric levels. P97-2 did show deviation. Interestingly, P97-2 was found to contain some amines and glycols while P97-1 and P97-3 are not impacted. Therefore, the presence of groundwater contamination correlates with oxygen consumption and carbon

dioxide evolution. What is not well understood is if the amines are necessarily the carbon source being used by the bioactivity.

To confirm the measured O_2/CO_2 tests and to measure rates of oxygen consumption, respiration tests were conducted on three of the piezometers (97-6A, 97-7A, and 97-11A). One set of tests was conducted shortly after piezometer installation and the other after the dewatering program. Both tests were conducted with the blower/vacuum pump turned off. Initially, the wells were aerated and bailed to ensure atmospheric oxygen levels in the well bore. An oxygen sensor (Jensen Instruments) was installed in each of the three wellbores and datalogged for a 24 hour period. Results for the first set of tests are presented in Figure 6. They demonstrate variable oxygen usage for the three wells. During the first test, the screen in 97-6A was covered in water, so only oxygen in the well bore was available and it was consumed relatively quickly. The order of the oxygen depletion rates for the three wells shown in Figure 6 reversed during the second test, indicating dynamic activity in the subsurface and a change perhaps caused by the de-watering program. Once again, there are a variety of reasons why the subsurface might act as an oxygen sink. The presence of multiple carbon sources as well as significant ammonia concentrations could all serve as mediums for oxygen consumption through aerobic degradation or nitrification.

3.4.2 Ethanolamine and ammonia levels.

As previously mentioned, the water encroachment in the bioventing system permitted a more thorough sampling program than would otherwise have been possible without extensive drilling. MEA is completely miscible with water and despite its reported sorption to soils (Sorensen *et al.*, 1997), will partition significantly into the aqueous phase. The ammonia at the pH values encountered at the site is in the ammonium ion species which is also very soluble and mobile in water. Water samples were taken before and after the dewatering bioventing program to determine if MEA degradation was occurring. According to the proposed pathways (Figure 1), ammonia should be evolved during the degradation of MEA. The concentrations ranged from below detection limit (BDL) to 36000 mg/L for the MEA and from BDL to 3700 mg/L for ammonia. Many of the samples contained levels of both MEA and ammonia that are well above levels reported to inhibit amine degradation (Sorensen *et al*, 1997) and nitrification (Vershueren, 1983). However, the site may have become acclimatized to high concentrations or degradation may be occurring at the fringe of the contaminant plume. Figure 7 presents a scatter and means plot for the MEA samples taken in wells before and after the dewatering program. Only the wells with data for both sampling programs were included. The overall mean MEA concentration has error bars that represent the 90% confidence interval. Thus we can say with 90% confidence that the overall average amine concentration was reduced during the dewatering program. In a similar plot prepared for the ammonia, there was an overall increase in the mean ammonia concentration by 300 mg/L, but no statistical difference. Thus MEA was reduced in concentration without a

significant change in ammonia levels. This result suggests that dilution is not the sole mechanism for amine reduction.

3.4.3 Microbiological tests

As a final inquiry to help elucidate whether the site had biologically active organisms, several microbiological tests were conducted on groundwater taken from piezometer 97-8B. The groundwater at 8B generally has several thousand mg/kg of both ammonia and MEA. Table 3 presents results from two water samples sent to Olds College for microbial analysis by Dr. Abimbola Abiola. The first sample was collected on October 15, 1998 during the aquifer test at 97-8B. The second sample was collected on October 26, 1998 from the pumped groundwater stored in the tank at the site. Despite the high levels of ammonia and MEA in the samples, total aerobic heterotrophs and total anaerobes were found in significant numbers (10^5-10^6 colony forming units per gram). This does not necessarily mean that there are viable amine degraders in the water, but suggests that the water is by no means sterile.

Table 3: Most probable number determination of aerobes and anaerobes.

Sample Name	Anaerobic Bacteria (cfu/g)	Aerobic Bacteria (cfu/g)
October 15, 1998: 97-8B	3×10^5	3×10^5
October 26, 1998: 97-8B	5×10^5	4×10^6

As a test to try and categorize the types of bacteria present at the site, Biological Activity Reaction Tests (BART™) donated by Droycon Bioconcepts Inc. were used (Droycon Bioconcepts Inc., 1998). The BART™ kits are tests which indicate the presence and approximate enumeration of different types of bacteria. Test types included heterotrophic aerobic bacteria, nitrifying bacteria, denitrifying bacteria, iron related bacteria and sulfate reducing bacteria. Two samples were used. The first sample was collected on October 15, 1998 from 97-8B shortly after starting the aquifer test. The second sample was collected from 97-8B on October 16, 1998 after 25 hours of pumping. Results are displayed in Table 4 and indicate widespread microbial activity in the groundwater except for nitrifying bacteria. This is consistent with the ammonia accumulation at the site since nitrifiers are necessary for the transformation of ammonia to nitrite and nitrate. It does raise the concern, however, that successful mineralization of MEA will not necessarily remediate soil and groundwater because of ammonia accumulation. As a secondary remedial step, it may be necessary to stimulate nitrifying organisms to ensure the complete minearalization of both amines and ammonia.

Table 4: Biological Activity Reaction Test (BART™) Results

Sample Name (97-8B)	Heterotrophic Aerobic Bacteria (cfu/mL)	Nitrifying Bacteria (cfu/mL)	Denitrifying Bacteria (cfu/mL)	Iron Related Bacteria (cfu/mL)	Sulfate Reducing Bacteria (cfu/mL)

Oct. 15, '98	10^6	No activity	10^6	$> 10^5$	10^3
Oct. 16, '98	10^6	No activity	10^6	$> 10^5$	10^2

4.0 Conclusions and Recommendations

A field research program was conducted at the site of a decommissioned natural gas sweetening plant to demonstrate the use of a combination of *in-situ* remediation methods. A shallow horizontal well was used to hydraulically induce twelve sand-filled fractures in the subsurface to increase the overall permeability of the porous media. The fractures were successfully introduced into the subsurface and were demonstrated to increase the overall permeability of the fractured region by at least one order of magnitude. Tensile failure of the PVC casing in the initial horizontal well was avoided in a subsequent well by using a pre-tensioned steel cable to reduce tension on the PVC during completion. The second well was not fractured and had relatively poor connectivity to the fracture network. While horizontal wells may provide an efficient means of installing a fracture network, fractured vertical wells may carry less risk of losing access to the whole network during well completion. Bioventing at the site was hindered by unexpectedly high water levels, but a subsequent dewatering bioventing program demonstrated a reduction in MEA concentration. Oxygen depletion, carbon dioxide production, and ammonia accumulation provide evidence of MEA biodegradation. Microbial activity in water samples is moderately high and indicates that despite the high levels of ammonia and MEA, the water is not toxic to all organisms. Bacterial testing provides preliminary evidence that nitrification is not occurring in the groundwater. This may prevent the assimilation of ammonia at the site and must be considered for the bioremedition of this site and others impacted with alkanolamines.

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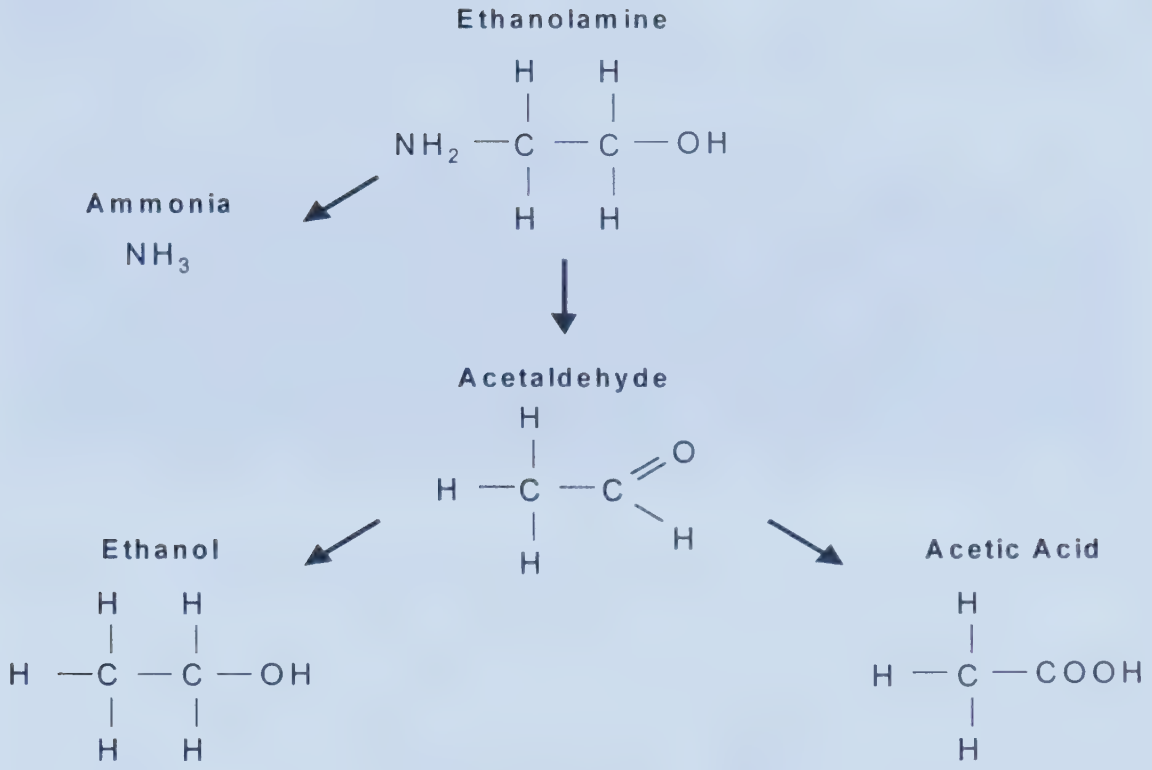

Figure 1 Proposed ethanolamine degradation pathway
(After Knapp *et al.*, 1996; Williams and Callely, 1982)

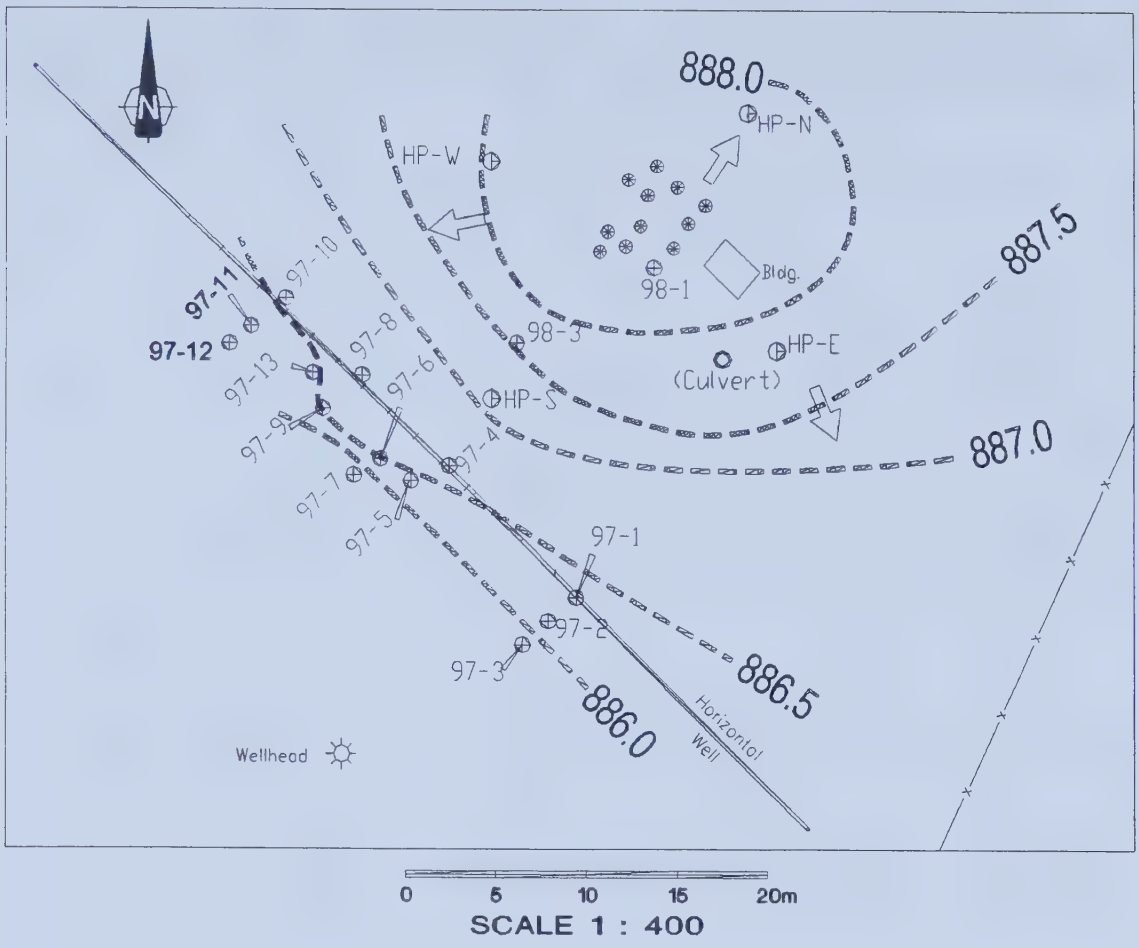

Figure 2 Field Site Schematic

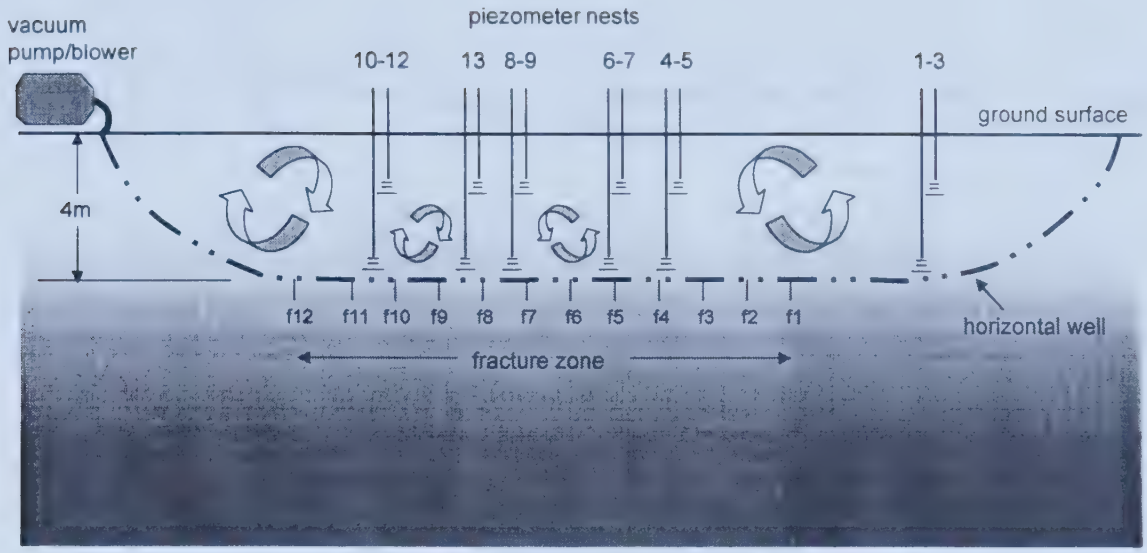

Figure 3 Sectional View Along the Horizontal Well

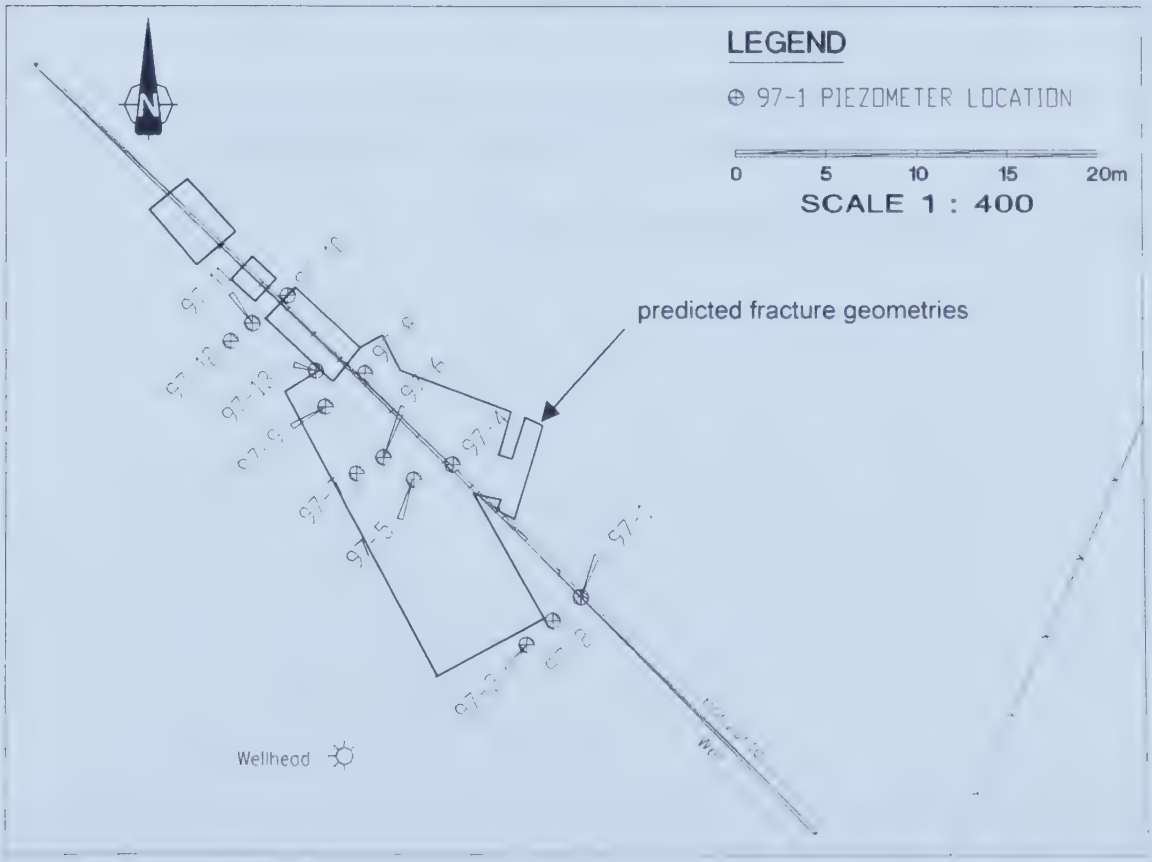

Figure 4 Predicted Fracture Geometries

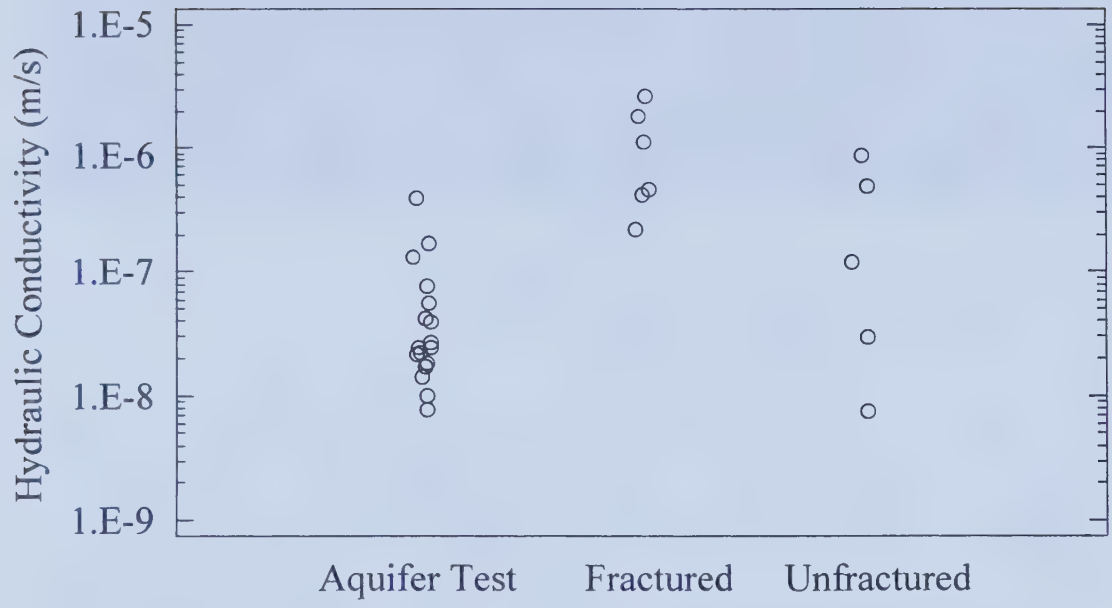

Figure 5 Hydraulic Conductivity Scatter Diagram

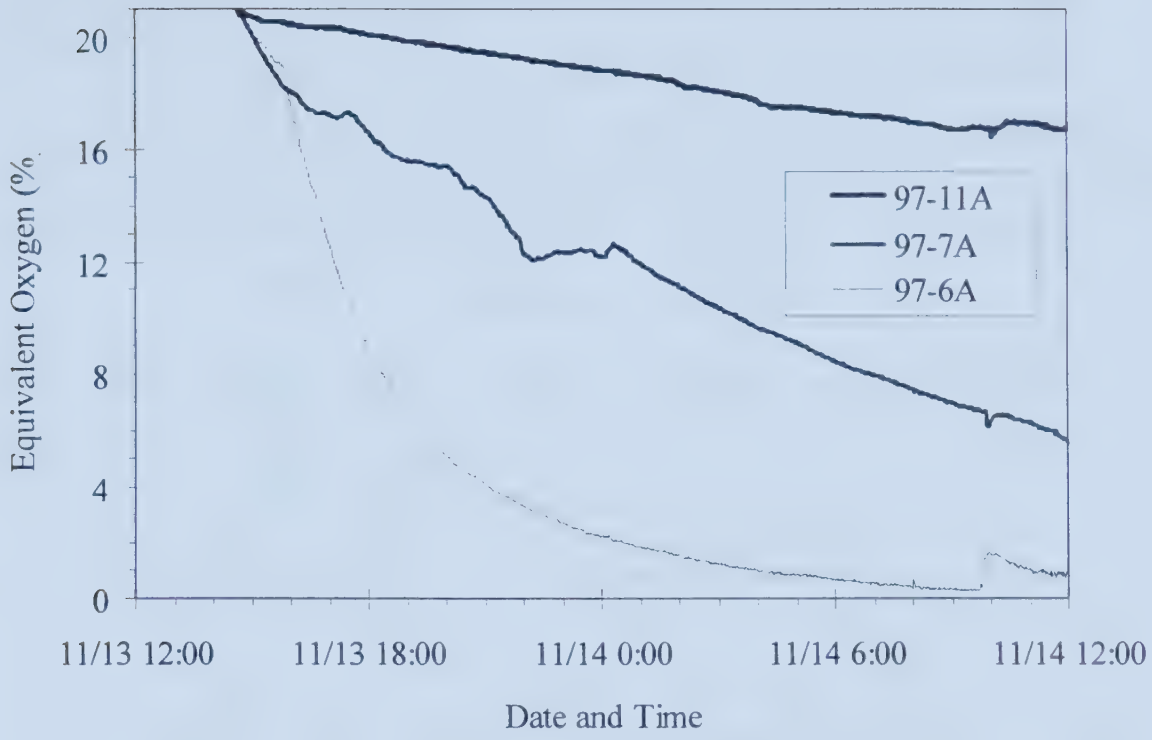

Figure 6 Oxygen Depletion Curves Measured during Initial Bioventing Program

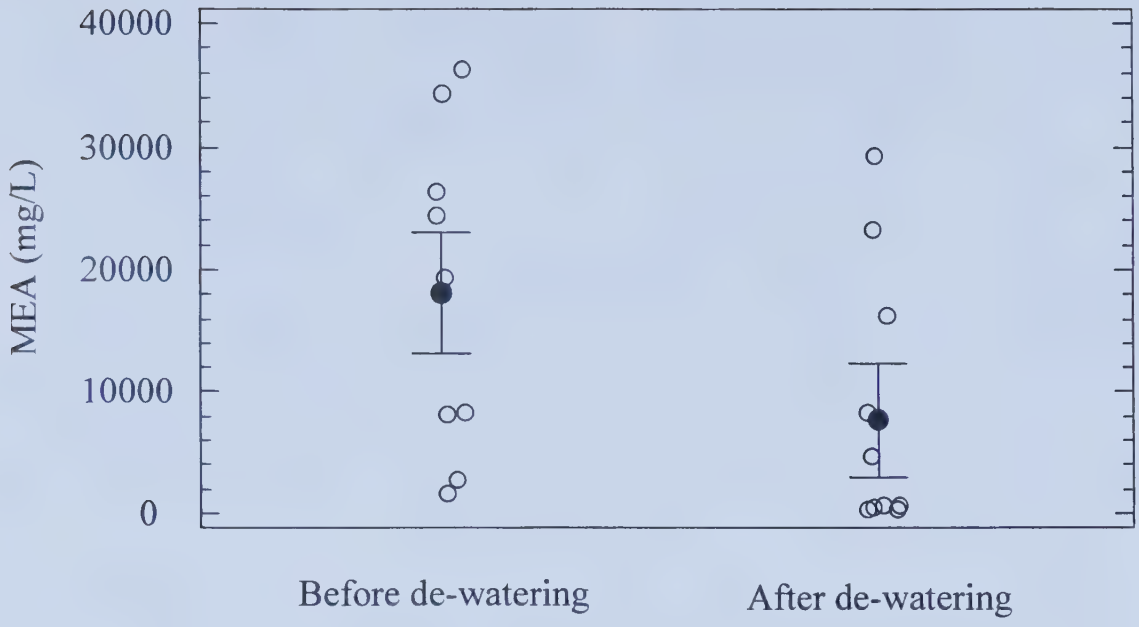

Figure 7 MEA Concentrations Measured before and after De-watering Program

Using Oily Waste to Restore Productivity in a Severely Eroded Loamy Sand*

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EXTENDED ABSTRACT

With progressive depletion of the more easily recoverable oil reserves in western Canada the volumes of waste generated during heavy oil production and processing are steadily increasing. The 600 million litres of heavy oil produced in 1998 accounted for 40% of the total oil production in all of Canada. The safe disposal of these heavy oil wastes has become an environmental issue. We believe agriculture can provide effective solutions for some of the oil and gas industry's disposal problems by utilizing the organic C-rich wastes to amend nearby areas of marginally productive cropland. Thus a recent field study in the Lloydminster region indicated that a single application of an EOR-type heavy oil production sludge to a Meota loamy sand, at 1 to 2% initial soil oil content, effected large and lasting increases in soil aggregation and an eventual 35 t/ha gain of humus through the microbial conversion of hydrocarbons. At present, the cultivated land base on the Prairies includes >3 million ha of sandy soils that are highly susceptible to erosion and are low in organic matter and productivity. Much of this marginal cropland could benefit from improvements in soil structure and humus content that can be realized through incorporation of organic, including petro-type, wastes. Consequently, the objectives of our field experiment at Richmound, SK are to generate benchmark data needed by regulatory agencies and by the oil and gas industry to jointly develop guidelines and protocols that will enable and control the future use of increasing volumes of hydrocarbon wastes - in an agronomically and environmentally sound manner - as soil amendments on private farmland in Alberta and Saskatchewan.

The AFIF-supported field study on a Hatton loamy sand near Richmound, SK consists of a 96 plot experiment with two cropping systems (i.e. fallow and cropped), two cereal crops (i.e. oats and wheat), three oily waste application levels (i.e., none, 1%, 2% soil oil

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* Presented at the 24th Annual Meeting of the Canadian Land Reclamation Association held jointly with the Saskatchewan Environmental Industry and Managers Association, Saskatoon, Saskatchewan, September 28-30, 1999.

content, wt/wt), two fertilizer treatments (i.e., none and best management practice), and four replications of all treatment combinations. The oily waste was applied and incorporated on November 5, 1997 by rototilling into the top 10 cm of the 2m x 12m plots. It originated from the Heavy Oil Upgrader of Consumers' Co-operative Refineries Ltd. in Regina SK and has a gross composition of 61% water, 31% hydrocarbons and 8% solids (clay). This sludge contains a total of 5,000 ppm of polynuclear aromatic hydrocarbons (PAH) with the two main PAHs being Dimethyl naphtalenes (1,500 ppm) and Methyl naphtalenes (1,300 ppm). In this study the oily waste is used as an amendment on sandy, erosion-prone farmland to induce stable soil aggregation and improve long-term crop productivity through the microbial conversion of hydrocarbons into humus. Consequently, timing and rates of N-and P-fertilizer applications were designed to optimize this soil microbial conversion process. Application of oily wastes to cropland to produce soil humus (stable organic matter) should sequester the bulk of the carbon in the soil rather than releasing it in form of CO_2 (i.e., one of the so-called 'greenhouse' gases) to the atmosphere, as occurs during burning or intensive 'land farming' of these wastes.

On this severely eroded loamy sand, that contained only 0.7% organic matter, the applied oily waste served initially as an effective 'glue' for binding and holding the sand grains together. Thus, by early spring 1998, the surface of the oiled plots showed no signs of topsoil loss to wind erosion while the unoiled control plots were littered with many rocks that became exposed as the surrounding topsoil had been swept away by strong Chinook winds. Rotary dry sieving showed a decrease in the wind erodible soil fraction (i.e., aggregates < 0.84 mm) of 9% where 1% oil was applied and a 13% decrease where 2% oil was applied. These reductions of the wind erodible fraction remained unchanged from spring 1998 to spring 1999. The resistance to erosion by water was also greatly increased as wet sieving, in spring 1998, indicated increases of 58% and 65% in waterstable aggregates where 1 and 2% oil had been applied, respectively. By spring 1999, the corresponding increases in waterstable aggregates were 44 and 71% due to soil incorporation of waste oil.

Enumeration of different types of microbes by soil dilution plating onto selective agar media indicated that the incorporation of oily waste sludge boosted most microbial populations when compared to unoiled control soil. The proportion of oil degrading organisms increased immediately severalfold and then decreased steadily over the next 11 months. The response to waste oil addition by soil bacteria and actinomycete populations occurred earlier than the response by filamentous fungi and yeasts. Heavy fertilization resulted in markedly reduced soil microbial populations and respiration, particularly at the 2% level of oil addition.

On April 15, 1998 the 48 plots on chemfallow were seeded to cereals, 24 plots to oats, cv. Calibre, and 24 plots to durum wheat, cv. Kyle. Due to poor emergence, probably caused by excessive moisture deficiency after the late fall rototilling and the lack of overwinter snowcover, all plots had to be reseeded on May 27, 1998. As a result of this late seeding and considerable early drought stress, crop growth and production was generally poor on

most plots. The results from manual harvest sampling in mid-August showed that on plots without oily waste-related fertilization, grain yield of oats was significantly increased at 1% soil oil content and was equal to the check yield at 2% oil. However, grain yields of durum at 1% oil were slightly lower than the check and at 2% oil in soil durum yield was severely depressed. On May 4, 1999, the previously fallowed 48 plots were seeded to oats and durum wheat and subsequent crop establishment was good with no adverse weather conditions. Plant emergence counts indicated there were no residual phytotoxic effects from the waste oil application on plant density or early development of either cereal. Manual sampling of the crop biomass at flowering, in mid-July, showed a two- to three-fold increase in durum production with 1% oil and a doubling of the check dry matter with 2% initial oil application. Oat biomass, production in the oiled plots was generally equal to the control and preliminary indications suggest that grain yields are markedly increased by waste oil application, particularly when combined with proper fertilization.

Our results, to date, confirm that some oil industry wastes can provide a very effective resource for the protection and improvement of sandy cropland and that this type of agricultural use could become a viable and cost-effective waste disposal alternative for the petroleum industry in western Canada.

Investigation of Microbial Bioremediation in a Gold Mill Tailings Pond*

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1. Introduction

Cameco Corporation's Contact Lake Operation was a small gold mine and mill located in central Saskatchewan approximately 45 km northeast of La Ronge. Untreated tailings slurry from the cyanide leach, carbon in pulp (CIP), mill were deposited in a partially dewatered lake (Turtle Lake) from December 1994 until June 1998. As expected, concentrations of cyanide and copper, the primary contaminants of concern, gradually built up over the first seventeen months of operation. There were no discharges from the tailings pond throughout this period and tailings supernatant was recycled to the mill for re-use as process water throughout the entire operating life of the mill. After cyanide and copper built up to approximately 45 - 50 mg/L in the tailings supernatant water, a dramatic decrease in both cyanide and copper concentrations occurred over a four month period. These reductions occurred despite the continued loadings being received from untreated mill tailings and the recycling of supernatant to the mill. Concentrations of cyanide and copper continued to decline over the rest of the operating period of the mill and continue to decline to this date. Microbial degradation was investigated as a possible explanation for the dramatic and continuing decrease in cyanide and copper concentrations in the tailings pond.

2. Methods

To determine if microbial degradation could be responsible for the changes in cyanide and copper concentrations, a three phase investigation was undertaken, with each phase building upon the results of the previous one.

2.1 Phase I

The first phase of the investigation involved microbiological characterization of the tailings pond. Samples of tailings solids and supernatant were collected in sterilized containers from several locations within the tailings pond. All samples from the mine site for this investigation (Phase I, II, and III) were packed with ice and transported to the laboratory within 48 hours. Microbiological characterization of the samples was conducted and included analysis for total coliforms (TC), fecal coliforms (FC), heterotrophic plate count (HPC) and total fungi count (TFC). The pour plate method was used for the determination of HPC and TFC in all samples using 1 mL aliquots for

* Presented at the 24th Annual Meeting of the Canadian Land Reclamation Association held jointly with the Saskatchewan Environmental Industry and Managers Association, Saskatoon, Saskatchewan, September 28-30, 1999.

testing. The membrane filtration and most probable number methods were used for the determination of TC and FC in liquid and solids samples, respectively, using appropriate aliquots of each sample for testing. Cultures isolated from this work were maintained and in some cases used in Phase II and/or III.

2.2 Phase II

The purpose of the second phase was to isolate and identify potential cyanide and copper degrading microorganisms from the tailings pond samples. An enrichment culture technique was used to isolate microorganisms capable of growing in the presence of the cyanide and copper concentrations present in the Contact Lake tailings pond. Furthermore, the use of a cyanide containing enrichment medium allowed for the isolation of microorganisms capable of utilizing cyanide as a nitrogen source after other sources of nitrogen had been exhausted.

A mixed bacterial culture was established by inoculating 20 mL of nutrient broth (DIFCO Laboratories) containing 1 mL liquid from tailings solid with colonies obtained from samples (solids and supernatant) in Phase 1. This culture was incubated under aerobic conditions for 72 hours in a water bath at 35 C under agitation at 200 rpm. This mixed culture was used to set up three enrichment cultures in 250-mL Erlenmeyer flasks. Each flask contained 50 mL of enrichment medium and 1 mL of culture suspension from the mixed culture. Two control flasks received 50 mL enrichment medium only. Enrichment medium was prepared from the undiluted mill tailings which were filtered through a Whatman No. 1 filter to remove sediment and sterilized by membrane filtration (0.45 m nitrocellulose membrane, Gelman). The flasks were incubated for 4 weeks at 25 C under aerobic conditions at an agitation rate of 200 rpm. The growth of enrichment cultures was monitored by taking weekly samples and plating on a set of duplicate plates of Standard Plate Count Agar (Oxoid). At each sampling interval (0, 1, 2, 3, 4 weeks), an aliquot of 1 mL suspension was spread on each plate from individual enrichment culture flasks. Growth in control flasks was examined by plating 0.2 mL inoculum onto each plate. For the enrichment cultures, serial dilutions were made using sterile diluent (0.1% Bactopeptone in water), whereas control cultures were plated directly. Plates were incubated at 35 C for 48 hours and colonies (colony forming units) were counted manually using the Quebec Colony Counter.

Five colonies were randomly picked as putative cyanide degrading cultures from the plates of 4th week enrichment cultures (three from culture #4 and one each from the other two cultures) and transferred to fresh Standard Plate Count Agar (SPCA) plates. Each of the five isolates was taxonomically identified using the API system (bioMerieux Vitek, Inc. Missouri, USA). Cyanide tolerance capacity of these cultures was further confirmed by their growth on SPCA medium supplemented with potassium ferricyanide (237 mg cyanide/mL). The isolated cultures were maintained by regular subculturing on SPCA medium supplemented with the filter sterilized mill tailings samples.

All cyanide, copper, and ammonia results reported here were analyzed at the Saskatchewan Research Council (SRC), Analytical Services Laboratory in Saskatoon, Saskatchewan. Samples were preserved appropriately before being shipped to SRC. Samples for total cyanide were preserved with NaOH to pH >12 and analysed by an automated colorimetric procedure using pyridine-pyrazolone and chloramine T with in-line distillation and UV digestion (Environment Canada NAQUADAT No. 06604). Total copper analysis on nitric acid preserved (pH <2) samples was conducted by Inductively Coupled Plasma Atomic Emission Spectroscopy. Sulphuric acid preserved (pH <2) samples were analysed for total ammonia as nitrogen by an automated phenate method (*APHA, 1995*).

2.3 Phase III

Cyanide degrading bacteria isolated in Phase II were tested in degradation trials. In addition to these bacterial isolates, an original inoculum (mixed culture) from Phase II and a fungal culture, isolated as a laboratory contaminant, were also tested. All cultures used in Phase III were grown under aerated conditions on a shaker at room temperature (22-24 C).

Seed inoculum was prepared by culturing the isolates in 30 mL of tryptic soy broth (TSB, DIFCO Laboratories) and incubating overnight at room temperature on a shaker at 200 rpm. The degradation trials were conducted by adding 15 mL of the culture suspension in the broth to 250 mL of the filter sterilized mill tailings in a 500 mL erlenmeyer flask. Flasks were incubated on a shaker with an agitation rate of 200 rpm at room temperature. A total of eight cultures were tested including four *Shewanella putrefaciens* isolates, one *Staphylococcus hominis*, one original mixed culture (ie., before enrichment culturing), one fungus (*Cladosporium sp.*), and one control. The control flasks contained filter sterilized mill tailings (250 mL) only. Four flasks were prepared for each culture at the start of the degradation trials and one flask was used for each of the four intervals: 0, 1, 2, and 4 weeks for analyses.

3. Results

3.1 Phase I

Microbial characterization (Phase I) of the tailings pond solids and supernatant samples indicated that most microbial activity was likely to be from heterotrophic bacteria as they were the most abundant and there were very low counts of coliforms and fungi (Table 1). A common trend in these results was that the greater number of microorganisms (bacteria and fungi) were found in solids samples compared to liquid (supernatant) samples. It was also noted that microbial numbers within the tailings pond were greatest at the sample location nearest the tailings deposition point. The presence of total and fecal coliforms was also found to be restricted to the sampling location nearest the tailings deposition point. The presence of coliforms at this location is not unexpected given the co-deposition of sewage and mill tailings.

Table 1

Phase I Results - Microbial Enumeration

	Solids		Supernatant	
	Range	Mean	Range	Mean
Heterotrophic[1] (HPC) Plate Count	1200-28800	10528	11-85	29
Total Fungi[1] (TF) Count	2-160	27	2-7	4
Total Coliforms[2] (TC)	<30 - 1900	418	<1 - 230	24
Fecal Coliforms[2] (FC)	<30 - 1900	418	<1	<1

[1] HPC and TF - results expressed as colony forming units per 1 mL sample.

[2] TC & FC - results expressed as colony forming units per 100 mL sample (liquid samples) or most probable number per 100 mL sample (for solids samples).

3.2 Phase II

Results from the weekly enumeration of the enrichment cultures from Phase II are given in Table 2. The mean bacterial count for the enrichment cultures decreased over the first two weeks and then increased in weeks three and four to a level equal to that at initiation. The bacterial counts for the two control flasks demonstrated the effectiveness of the filter sterilization performed on the mill tailings which were used in preparation of the enrichment medium.

Five putative cyanide degrading cultures were isolated from the enrichment cultures. The isolates were identified to species level based on morphological characters, physiological tests and the API system. Results of these tests are given in Table 3. Four of the bacterial isolates were identified as *Shewanella putrefaciens* and one as *Staphylococcus hominis*. These cultures were used in the Phase III degradation studies.

A fungal culture isolated as a contaminant in the laboratory during early biodegradation work was identified, by microscopic examination, as *Cladosporium sp.* This fungus is a plant pathogen and therefore considered a contaminant of the tailings pond samples. However, as it demonstrated a tolerance for the cyanide and copper concentrations in the tailings pond, it was also studied for its potential biodegradation abilities in Phase III under similar aerobic conditions as for the bacterial cultures.

Table 2

Total Aerobic Bacterial Count in Enrichment Culture for Four Week Incubation

Flask Identification	Counts (CFU) per mL of sample				
	Week 0	Week 1	Week 2	Week 3	Week 4
Control #1	<1	2	<1	<1	<1
Control #2	<1	<1	4	<1	<1
Culture #3	6.85×10^7	1.06×10^7	5.80×10^5	1.58×10^5	5.70×10^4
Culture #4	1.35×10^7	1.11×10^7	8.45×10^5	1.40×10^7	7.50×10^7
Culture #5	1.85×10^7	1.63×10^7	6.15×10^5	1.00×10^5	5.00×10^5
Mean (Culture 3-5)	3.35×10^7	1.27×10^7	6.80×10^5	4.92×10^6	3.78×10^7

Table 3

Microbiological Identification Data

I.D.#	Cameco #1	Cameco #2	Cameco #3	Cameco #4	Cameco #5
Colony Morphology	Gram (-) rods	Gram (-) rods	Gram (-) rods	Gram (-) rods	Gram (+) cocci
Media	TSA	TSA	TSA	TSA	TSA
Growth	35 C	35 C	35 C	35 C	35 C
Size	Large	Large	Large	Large	Large
Pigmentation	Creamish	Creamish	Creamish	Creamish	White
Elevation	Convex	Convex	Convex	Convex	Flat
Edge	Fuzzy	Fuzzy	Fuzzy	Fuzzy	Round
Physiology					
Catalase	+	+	+	+	+
Oxidase	+	+	+	+	+
Growth*	++++	++++	++++	++++	+
Result	Shewanella putrefaciens	Shewanella putrefaciens	Shewanella putrefaciens	Shewanella putrefaciens	Staphylococcus hominis

* growth on *Pseudomonas* medium

3.3 Phase III

A summary of results from the Phase III degradation trials is provided in Table 4 and a plot of the cyanide and copper concentrations over the four week trials is given in Figure 1. As these results demonstrate, all degradation trial flasks showed dramatic reductions in total cyanide, and to a slightly lesser extent, total copper concentrations. Per cent reductions for total cyanide over the four-week test, ranged from 98.04 to 99.83% and from 67.30 to 93.42% for total copper. In comparison, the control flask showed a 13.58% reduction in total cyanide concentrations over the four-week test. Total ammonia as nitrogen levels for each treatment at the end of the four-week degradation trials are also given in Table 4. Although ammonia concentrations were not determined for each treatment on day zero, the final levels can be referenced to an initial value of 12.3 mg/L. This is the result of a single analysis conducted on the filter sterilized tailings (corrected for addition of microbial culture) used in the degradation trials. Although no quantitative conclusions should be made from these results, they do indicate that a substantial increase in total ammonia levels occurred over the course of the degradation trials.

A meaningful comparison of the reductions in copper between the inoculated flasks and the control was not possible due to sampling difficulties and unexplainable fluctuations in control flask copper concentrations. The week one control flask copper and cyanide values were lower than week two or four results (Table 4). It is believed that the formation of a precipitate in week one flasks is responsible for the lower values in week one. A precipitate was observed in the week one control flasks and remained stuck to the flask wall while sampling. Therefore, the retention of copper and cyanide in this precipitate would explain the low values measured in the week one flask. This explanation is further supported by the copper and cyanide values for weeks two and four when no such precipitate was observed in these control flasks. We are unable to offer an explanation for the elevated copper values in the week four flask.

The *S. hominis* culture showed the greatest per cent reduction in total cyanide concentrations but also had the lowest per cent reduction for copper. The fungal culture (*Cladosporium sp.*) showed the greatest reduction in copper concentrations. This culture and the mixed culture had greater reductions in copper than any of the single species bacterial cultures. The total cyanide concentrations at the end of the four week degradation trial in the *S. putrefaciens* #3, *S. hominis* #5, and mixed culture were below the regulatory agency imposed discharge limits (1.0 mg/L monthly mean) for the site. These dramatic reductions were achieved despite starting concentrations of nearly 400 mg/L total cyanide. All of the total copper concentrations at the end of the degradation trials were at least an order of magnitude greater than regulatory discharge limits (0.30 mg/L monthly mean).

4. Discussion

The results of this investigation have demonstrated that a number of specialized microorganisms were present in the Contact Lake tailings pond, which were tolerant of significant cyanide and copper concentrations. Generally, a greater number of microorganisms were found in samples of the (subaqueous) tailings solids than in samples of tailings pond supernatant (liquid). Also, greater numbers were found in the samples closest to the tailings deposition point, perhaps implying a relationship or even dependence on cyanide in the tailings.

Table 4. Phase III Results - Biodegradation of Cu and CN

Treatment	Time	Total CN (mg/L)	% Degradation (CN)	Total Cu (mg/L)	% Degradation (Cu)	Total Ammonia as Nitrogen (Mg/L)
Control	0 day	346		180		
	1 week	155	55.20	63	65.00	
	2 week	340	1.02	220	-ve	
	4 week	299	13.58	530	-ve	10
S. putrefaciens#1	0 day	578		162		
	1 week	162	71.97	59	63.58	
	2 week	92	84.08	21	87.03	
	4 week	11.3	98.04	18	88.88	45
S. putrafaciens#2	0 day	328		156		
	1 week	144	56.09	62	60.25	
	2 week	59.1	81.98	59	62.17	
	4 week	1.27	99.74	51	67.30	43
S. putrafaciens#3	0 day	378		156		
	1 week	117	69.04	59	62.17	
	2 week	77.2	79.57	59	62.17	
	4 week	0.952	99.74	50	67.94	46
S. putrafaciens#4	0 day	444		152		
	1 week	147	66.89	64	57.89	
	2 week	83.1	81.28	13	91.44	
	4 week	2.260	99.49	47	69.07	49
S. hominis#5	0 day	386		156		
	1 week	138	64.24	44	71.79	
	2 week	12.00	96.89	61	60.89	
	4 week	0.650	99.83	51	67.30	48
Mixed culture	0 day	372		160		
	1 week	119	68.01	57	64.37	
	2 week	33.3	91.04	61	61.87	
	4 week	0.885	99.76	19	88.12	47
Cladosporium sp.	0 day	346		152		
	2 week	21.2	93.87	130	14.47	
	4 week	1.130	99.67	10	93.42	48

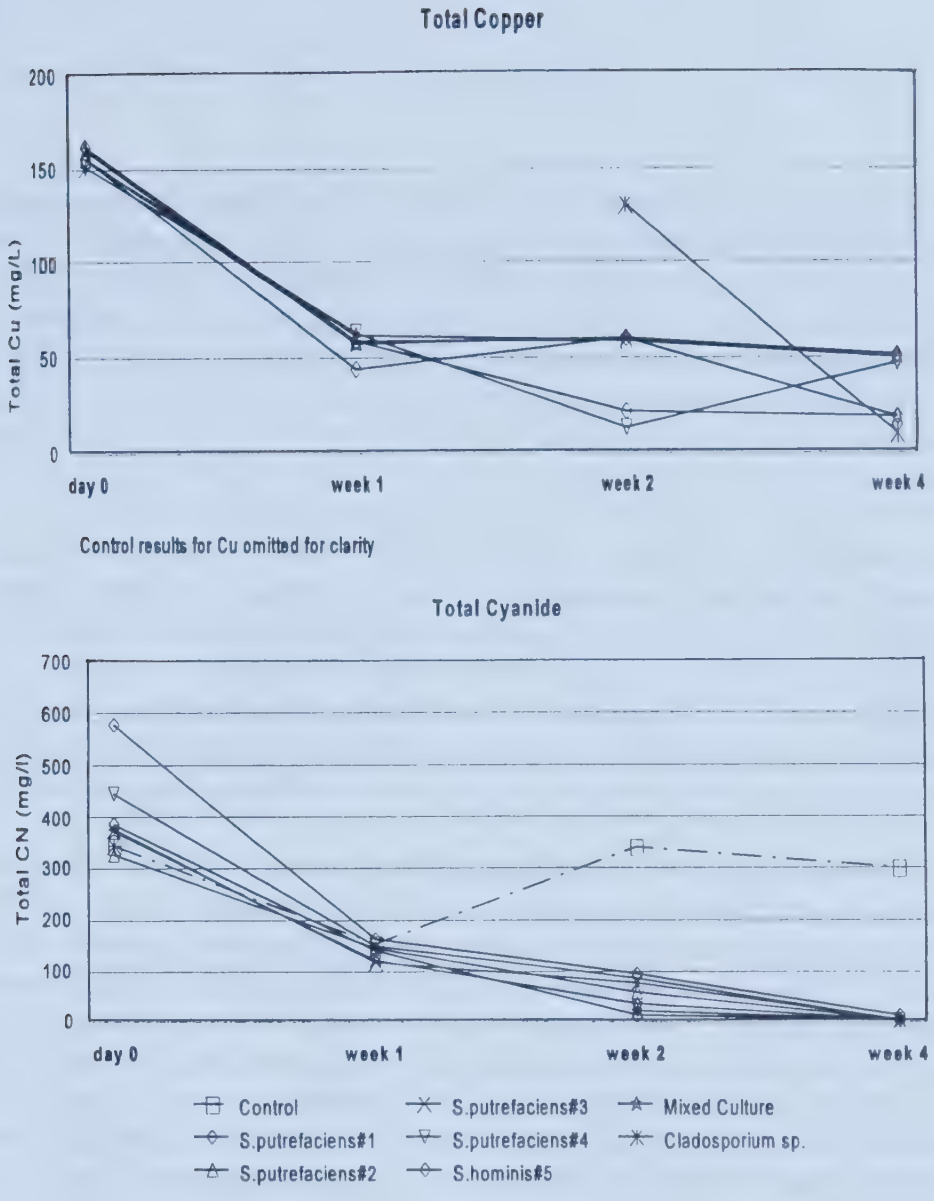

FIGURE 1

Phase III Results - Plots of copper and cyanide concentrations over 4 week degradation trials

By using enrichment culture techniques, specialized microorganisms capable of utilizing cyanide as a nitrogen source were isolated from tailings pond samples. Although non-cyanide nitrogen sources were initially present during enrichment culturing, it is believed that the incubation time was long enough for these to be exhausted, thereby providing the advantage to microorganisms capable of utilizing cyanide as a nitrogen source. Numerous other authors have successfully used enrichment culturing to isolate cyanide utilizing microorganisms (*Harris and Knowles, 1983. White et. al., 1988, Kang and Kim, 1993, Thompson et. al., 1995a*).

Two species of bacteria were isolated as potential cyanide degraders. *Staphylococcus hominis* is a gram positive cocci and is an opportunistic human pathogen. Its presence is attributable to the sewage which was co-deposited with mill tailings. It is interesting to note the very low numbers of total and fecal coliforms in all of the tailings samples, indicating an intolerance of coliform bacteria to conditions in the tailings pond. The second bacterium, identified as *Shewanella*

putrefaciens, is a gram negative, rod-shaped bacteria. It is very common in a wide range of environments including aquatic reservoirs (freshwater, marine, sewage), industrial sludges (mining, oil and gas), soils, and some food products (*Khashe and Janda, 1998*). While *S. putrefaciens* has occasionally been implicated as a human pathogen, it is reported to be most frequently recovered from non-human sources (*Khashe and Janda, 1998*). Therefore, it is uncertain whether the presence of *S. putrefacients* in the tailings pond is a remnant from before the lake (now tailings pond) was dewatered or it was introduced as a result of sewage disposal during operations.

In addition to the two bacterial species, a fungus, *Cladosporium sp.* was also found to be tolerant of the high cyanide and copper concentrations in the mill tailings. However, this fungus is a plant pathogen and a tailings pond is not considered its likely habitat and therefore it was considered a laboratory contaminant. Regardless of this, it demonstrated not only a tolerance for cyanide and copper but also a biodegradation ability under similar aerobic conditions as tested for the bacterial cultures. This ability is not unusual as numerous other fungi have been reported to biodegrade cyanide *(Nazy and Knowles, 1981, Nazy et. al., 1983, Allen and Strobel, 1966*).

Under laboratory conditions, all of the inoculated degradation trial flasks showed very large reductions in total cyanide (>98%) and total copper (67-93%) concentrations over the four-week test period. In comparison, the control samples, which were not inoculated, only showed a marginal reduction (13.58%) in total cyanide concentrations over the four-week test period. This indicates that the reductions in total cyanide were a result of biodegradation rather than other physical or chemical factors associated with the test procedure such as ultraviolet degradation, shear stress, or complexation or adsorption to other constituents in the sample matrix. The biodegradation of cyanide by microorganisms has been reported in numerous environments including river sediments, soils, coal tar sludge, sewage plant sludges, and heap leach waste piles (*Harris and Knowles, 1983, Castric, 1981, Kang and Kim, 1993, Raef et. al., 1977, Knowles, 1976, Thompson et. al., 1995*a). Furthermore, engineered systems have been designed and used specifically for the bioremediation of cyanide containing mine wastes, primarily at heap leach operations (*Thompson and Jones, 1993*), and other industrial waste waters (*Richardson, 1987, Ingvorsen and Godtfredsen, 1988*).

While all of the inoculated degradation trial flasks showed significant reductions in total copper, results from the control flasks were ambiguous. As a result, the copper reductions observed in the inoculated flasks can not definitively be attributed to the presence of the microorganisms. However, the simultaneous removal of metals, including copper and selenium, and cyanide degradation by specialized bacteria has been demonstrated in biodegradation studies involving mining wastes (*Fischer et. al., 1995, Adams et. al., 1996*). *Fischer et. al.* also reported some anomalous copper results in biotreatment studies involving simultaneous copper removal and cyanide degradation by a consortium of microbes. They also stated that when cyanide is biologically removed from solution, metals may also be precipitated by several possible mechanisms, including: adsorption on cell membranes, chelation, ligand depletion, or sulphide precipitation mediated by sulphate-reducing bacteria. *Thompson et. al., (1995b)* also found that

metals were removed from solution, remineralized, and deposited on the surfaces of spent ore particles during biodetoxification of a heap leach pad. In this investigation, biologically catalysed precipitation reactions are the most likely mechanism for the reduced copper levels given the use of filter sterilized mill tailings (i.e., no particulate matter or bacterium other than test inoculum). However, the simultaneous biomineralization of copper and biodegradation of cyanide could certainly occur in the tailings pond at the Contact Lake Operation.

The mechanisms involved in microbial cyanide biodegradation are not completely understood and a determination of the mechanism responsible for the results reported here was beyond the scope of this investigation. However, significantly higher ammonia concentrations were observed at the end of the degradation trials than in the original mill tailings used for these degradation trials. This suggests that the cyanide was metabolized by the microorganisms and used as a nitrogen source to support the growth of the organism rather than simply assimilating it. The literature indicates a number of possible reactions responsible for cyanide metabolism by microorganisms including substitution/addition, hydrolysis, oxidation, and reduction (*Raybuck, 1992, Mosher and Figueroa, 1995*).

5. Conclusions

In conclusion, microbial characterization of gold mill tailings pond samples (supernatant and solids) revealed a number of microorganisms which were tolerant of the elevated concentrations of metals and cyanide in the tailings pond. By the use of enrichment culturing techniques, two species of bacteria (*Staphylococcus hominis* and *Shewanella putrefaciens*) were isolated from the tailings pond samples and considered to be potential biodegraders of cyanide and copper. Degradations trials conducted using these two bacterial isolates, an original inoculum (mixed culture), and a fungal culture (*Cladosporium sp.*) isolated as a laboratory contaminant showed considerable reductions in total cyanide and copper concentrations for all trials. These bacteria and fungus were able to tolerate the very high concentrations of total cyanide (328-578 mg/L) and total copper (152 - 162 mg/L) in full strength mill tailings at the beginning of the trials and reduced levels to as low as 0.65 mg/L total cyanide and 10 mg/L total copper. To our knowledge, *S. hominis*, *S. putrefaciens*, and *Cladosporium* sp. have not previously been reported to biodegrade cyanide or copper. Results of this investigation demonstrated that a process of microbial bioremediation was a viable explanation for the dramatic reductions observed in Contact Lake Operation tailings pond cyanide and copper concentrations. The results also demonstrated that the disposal of sewage in the tailings pond was partially, if not fully, responsible for the presence of bacteria capable of degrading cyanide and copper.

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Use of Crop Selection and Cattle Manure to Bioremediate a Heavy Oil-Polluted Loamy Sand for Grain Production*

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ABSTRACT

The study reported here is an offspring from a 6-year field study near Maidstone, SK that was originally designed to assess the feasibility of utilizing a heavy oil production waste to improve erodible, sandy cropland through oil-induced stable soil aggregation and microbial conversion of hydrocarbons into humus. In one of our two plot experiments on a Meota loamy sand initial soil oil contents in the top 10 cm were much higher than anticipated, i.e. 7.0% and 3.0% instead of the targeted 1 and 2%, inadvertently rendering that experiment into an 'oil spill remediation' study. Early attempts to remediate the 'overoiled' soil with more tillage and greatly increased N + P + S fertilization failed to improve soil conditions enough to allow any crop growth. Thus we focused on screening for crops with higher tolerance to oily residues and on amending the polluted soil with an application of 63 tonnes (t) dry wt/ha of old cattle manure, containing 20 t OM/ha with a C/N ratio of 10.5. The main objectives of our study were (i) to assess the restorative ability of manure for soil properties critical to plant growth, and (ii) to measure manuring benefits for grain production by more oil-tolerant crops. Greenhouse and field tests indicated that cereals, as a group, are less sensitive than pulses, forages and oilseeds toward oily residues in soil. Among the cereals, oat was by far the most tolerant crop with wheat a distant second but well ahead of barley and rye. Within 4 months of manure incorporation there were marked improvements in soil properties that are indicative of soil quality and productivity. In unfertilized plots manuring effected a 20% reduction of the erodible fraction (<0.84 mm), 30% increase in waterstable aggregates, 20% decrease in bulk density, 56% increase in hydraulic conductivity and a 131% increase in viable bacteria. The effectiveness of manure in improving soil conditions was found to decrease with increasing rates of previous fertilizations. One year later, the overoiled plots were seeded to oat and wheat but due to extensive damage by grasshoppers only manure effects on emergence and vegetative growth up to flowering could be

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measured. In unfertilized plots manuring increased oat plant density by 53% and DM production by 150% relative to the unmanured check. Corresponding increases with wheat were 55% for stand density and 65% for biomass production. Stand densities and vegetative growth in overoiled, but manured, plots were very similar to those of unoiled controls emphasizing the effectiveness of a single manure application in restoring crop productivity to a heavy oil-polluted soil. Two years after soil incorporation of manure all plots were seeded to oats that were grown to maturity. When averaged across fertilizer treatments, manuring resulted in a 55% increase in plant density, 70% increase in crop biomass and an 82% increase in grain yield. There was also a significant positive interaction between manuring and earlier fertilizations in enhancing oat growth and particularly grain yield. On manured, but unfertilized plots the grain yield was 32% greater than on the corresponding unoiled and unmanured plots which attests to the restorative ability of decomposed cattle manure for cereal production. Manuring was also found to improve grain quality by maintaining protein levels and by markedly increasing kernel size and test weight of the oats. Thus we can conclude from this field study that a single application of old manure can be very effective in improving critical soil properties and, in turn, restoring the oil-polluted topsoil to full productivity in terms of grain yield and quality within one to two years.

INTRODUCTION

When oil spills happen in the Prairie region they frequently occur in or near fields of annual crops such as cereals, oilseeds and pulses. When a spill is rated as 'medium' (i.e. >4% oil in topsoil) or 'heavy' (i.e. >8.5% oil in soil) the affected area must be treated or it will remain unproductive for years (Toogood and McGill 1977). Spill studies in Alberta demonstrated that crop yields can be restored but only if microbial activity in the polluted soil is stimulated by frequent tillage and massive applications of fertilizer nutrients (Toogood 1977; McGill et al., 1981). However, there are instances, including the present study, when tillage and fertilization have failed to remediate polluted cropland in a timely fashion.

The study reported here is an offspring from a 6-year field study by Agriculture and Environment Canada with P.E.R.D. funding to assess the feasibility of utilizing heavy oil production wastes for protection and potential improvement of erodible, sandy cropland in northwestern Saskatchewan. Originally this research was focused on improving marginally-productive, arable land through oil-induced stable soil aggregation and microbial conversion of hydrocarbons into humus rather than to emphasize industrial disposal goals.

We found that a single application of a heavy oil sludge and incorporation into Meota loamy sand, at 1 to 2% initial soil oil contents, effected large increases in size and stability of aggregates (Rasiah et al., 1997) and eventually resulted in an average gain of 35 tonnes (t) of humus per hectare (ha) without any residual oil in soil or migration of organic pollutants into the groundwater (Biederbeck et al., 1993). It seems that many of the >3 million ha of cultivated sandy soils on the Prairies could benefit from improvements in soil structure and humus content that can be realized by incorporation of organic, including petro-type, wastes (Biederbeck et al., 1997). However, in one of our two plot experiments initial oil contents in the top 10 cm of soil

were much higher than anticipated, i.e. 7.0% and 3.0% instead of the targeted 1 and 2%, inadvertently rendering that experiment into an 'oil spill remediation' study. At first we attempted to remediate the 'overoiled' soil with more frequent tillage and greatly increased N + P + S fertilization but these practices failed to improve soil conditions enough to allow any crop growth. Thus we focused subsequent reclamation efforts on screening for crops with greater tolerance to oily residues and on amending the polluted soil with a massive application of old cattle manure, because livestock manures had already been shown to be more effective than chemical fertilizers in restoring productivity to artificially eroded soils in western Canada (Dormaar et al., 1988; Larney and Janzen 1996). The main objective of our spill remediation study was, therefore, to assess the restorative ability of manure for those soil properties that are critical to plant growth and for grain production by more tolerant crops on an oily waste-polluted loamy sand.

MATERIALS AND METHODS

Details of experimental design, research methodology and sampling techniques were as described previously by Biederbeck et al. (1993). In June and September 1986, two plot experiments were established on 2 ha of Meota loamy sand (Black Chernozemic soil) 10 km southeast of Maidstone, SK. The topsoil (0-10 cm) at the site had the following main properties: 80% sand, 9% silt and 11% clay; pH=5.8, EC=0.54 dS/m, BD=1.31 g/cm^3, CEC=5 meq/100g; 2.20% organic C, 0.184% total N and a C/N ratio=12.0 prior to oily waste sludge application. In both experiments, the same 3 sludge (00=none, 01=300 and 02=600 tonnes/ha) and fertilizer rates (F0=none, F1=150 kg N + 15 kg P + 24 kg S, and F2=300 kg N + 30 kg P + 48 kg S/ha) were applied to reach targeted waste loadings of 1.0 and 2.0% oil in soil (wt/wt), respectively. The EOR sludge was hauled from Husky's Fireflood Plant #4 near Maidstone. All 9 sludge x fertilizer combinations were replicated 3 times on 27 plots (4 x 14 m) per experiment. Fertilizer was broadcast and then sludge was applied and incorporated to 10 cm depth with a modified rotovator connected through its Bowie pump to a tank truck running alongside. Soils in all plots were sampled hydraulically to 120 cm depth just before sludge application in 1986 and then each spring and fall for routine physical and chemical analyses. The surface 10 cm were sampled manually for soil structural, biochemical, microbiological and hydrocarbon analyses.

In the first experiment, initial oil contents averaged 1.0 and 1.5% of soil in 01 and 02 plots, respectively. However, in the second experiment, initial oil contents were much higher averaging 7.0% in 01 and 3.0% in 02 plots due to extreme variability in oil content of EOR sludge from one truckload to another. In the plots with 7% oil content, and where no plants could grow in 1987, the soil was rototilled more often (fall and spring) and the fertilizer rate was increased in April 1988 to F4=600 kg N + 60 kg P + 96 kg S/ha to attempt remediation of the polluted soil.

During the winter of 1987/88, greenhouse tests were conducted to assess the response of various agricultural crops to soil-incorporated EOR sludge using bulk samples collected from 00, 01 and 02 plots of the second experiment in October 1987. Average oil contents of samples from 01 and

02 plots were 5.0 and 2.2%, respectively. Test plants included forage grasses and legumes, cereals, oilseeds and pulse crops. On May 17, 1988, each plot in the second experiment was divided along the length into 5 subplots (2.8 m x 4 m) and seeded to the following 5 annual crops, that had shown promising results during the earlier emergence tests in the greenhouse:

1) spring wheat, cv. Katepwa, at 82 kg/ha
2) oats, cv. Calibre, at 57 kg/ha
3) barley, cv. Leduc, at 68 kg/ha
4) spring rye, cv. Gazelle, at 61 kg/ha
5) field peas, cv. Trapper, at 178 kg/ha.

At maturity a 1.0 m^2 area was hand cut in each subplot for subsequent threshing and yield measurements.

In 1989, all plots were summerfallowed, receiving a total of 4 tillages: rototilling in spring and fall and cultivating twice in summer for weed control. On May 17, 1989, a mixture of well rotted barnyard manure and sand from a nearby farm was applied with a manure spreader to half the width of each of the nine 'overoiled ' 01 plots in the second experiment and was incorporated to 10 cm soil depth with the rotovator. A total of three loads of manure were used and subsequent sampling of the surface-spread material on all plots, prior to rototilling, indicated an average application of 97 tonnes wet weight or 63 tonnes dry weight or 20 tonnes of organic matter/ha. This well aged (>3 yr) cattle manure had an average C/N ratio of 10.5, indicating that it had undergone extensive decomposition. On May 18, 1990, half the length of each plot in the second experiment was seeded to wheat, cv. Katepwa, at 86 kg/ha and the other half to oats, cv. Calibre, at a rate of 88 kg/ha. A very severe grasshopper infestation after mid-June caused progressive crop damage, despite repeated spraying with deltamethrin. Thus plant dry matter of both cereals, when sampled at flowering, was markedly reduced and there was not enough grain left to harvest any plot at maturity. In spring 1991, all plots were seeded to oats and, with frequent and timely applications of various insecticides and border planting of deterrent crops, reasonable grasshopper control was eventually achieved. In late August, m^2 samples of oats were collected from the manured and unmanured halves of each plot for determination of plant populations, dry matter production, grain yield and grain quality.

RESULTS AND DISCUSSION

The effects of oils on plant growth can range from kill on contact and other direct physical damage, such as inhibition of seed germination, to growth reductions from indirect effects due to changes in soil moisture retention, reduced nutrient availability and development of anaerobic conditions and on to stimulation of growth at very low concentrations of hydrocarbons (Deuel 1990). The degree of toxicity also depends on the chemical nature of the hydrocarbons and generally decreases with an increase in molecular size and viscosity (McGill et al., 1981). Thus fuel oils are more phytotoxic than unrefined oils or heavier sludges.

Crop Selection for Tolerance to Oily Residues

The response of various crops to the previously soil-incorporated EOR waste sludge was assessed in the greenhouse by placing bulk soils, collected from the top 10 cm of selected plots at 13 months after sludge application, in wooden trays and measuring the relative rate of emergence on test plants

Table 1. Emergence of ten test crops in Meota loamy sand containing an average of 2.2% (02F2) and 5.0% (01F2) oil, when removed from plots for plant assays in the greenhouse.

Plant type and cultivar	Relative Emergence (% of unoiled soil)†	
	02F2	01F2
Sweetclover, cv. Norgold	0	0
Alfalfa cv. Rambler	137	49
Crested Wheatgrass, cv. Parkway	88	15
Bromegrass, cv. Carlton	150	75
Red Clover, cv. Norlac	88	31
Canola, cv. Tobin	37	1
Wheat, cv. Katepwa	83	71
Pea, cv. Trapper	188	37
Oat, cv. Calibre	120	82
Barley, cv. Klages	120	85

† Each number is the mean of three replicates per treatment

seeded at recommended rates and at optimum depth and then maintained at optimum soil moisture (field capacity). The cultivars of forage and field crops tested were chosen according to published recommendations from Saskatchewan Agriculture for crop production in the Black soil zone. Final seedling counts, as a percentage of those in the unoiled control soil, are shown in Table 1. At the 2.2% soil oil content, the effects ranged from complete inhibition of germination (sweetclover) to stimulation (alfalfa, bromegrass, pea, oat and barley). At the high oil level (5.0%), germination of all crops, except pea, was reduced and among the cereals only oat and barley emerged at a rate greater than 80% of the control. At both oil contents, canola had the lowest tolerance of any annual crop (Table 1). In a second test fungicides were used to prevent soil-borne diseases and then oat was the only crop able to germinate and emerge at both soil oil contents while wheat emerged well at 2.2% oil and pea, which appeared so tolerant in the first test, was severely inhibited (data not shown).

To further explore the issue of plant tolerance to oily residues, five annual crops with promising results from the greenhouse tests were evaluated under field conditions on the overoiled plots near Maidstone, SK in 1998. Analyses of soil samples, taken from these plots in spring 1988, indicated that oil contents in the top 10 cm averaged 2.1% (range 1.7 to 2.5%) in 02 and 4.6% (range 2.8 to 6.1%) in 01 plots prior to seeding the five subplots per plot. All yield data for grain

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and straw were averaged across the three fertilizer rates and are expressed as a percentage of the corresponding yield in the unoiled control plots (Table 2). The main conclusion from these results is that under field

Table 2. Yield of five annual crops grown on 'overoiled' plots of Meota loamy sand in the drought of 1988 (i.e. 2 yrs after heavy oil sludge application).

Avg. topsoil oil content in April 1988 (%)	Relative yield (% of unoiled treatment)†		
	Total biomass	Grain	Straw
	Barley		
2.1	8	8	8
4.6	0	0	0
	Oat		
2.1	150	171	142
4.6	4	6	3
	Pea		
2.1	0	0	0
4.6	0	0	0
	Rye		
2.1	2	2	2
4.6	0	0	0
	Wheat		
2.1	28	28	28
4.6	0	0	0

† Each number is the mean of three replicates per treatment.

conditions, oat was much more tolerant of oily residues than any of the other crops tested. At the lower oil content oat grain yield was actually increased by 71% over the control, but at 4.6% oil the yield was still 94% below the control. The only other crop that exhibited any reasonable tolerance of oily-residues was wheat. The failure of barley to tolerate these oily residues (Table 2) was disappointing as the well known salt tolerance of this crop would enable it to cope well with the high salt concentrations found in soils following EOR sludge applications. Except for the remarkably greater oil tolerance by oat, the results from our greenhouse and field tests are generally consistent with previous studies in central Alberta showing canola to be very sensitive to oil, barley as quite sensitive and wheat as moderately tolerant (Toogood and McGill 1977). However, our findings strongly disagree with the oil tolerance ratings for selected crops reported from the southern US (Deuel 1990) which assign a higher level of tolerance to peas, clover and perennial grasses than to wheat and oat.

Effect of Manure on Soil Properties

To be effective in restoring crop productivity to an oil-polluted soil, the application of manure must not only stimulate the microbial decomposition of oily residues but it must also improve the soil's structure and render conditions more favorable for plant growth by reducing soil compaction,
increasing aeration and tilth and by optimizing soil water and nutrient dynamics. The size distribution of aggregates is commonly used to assess soil structure and is recognized as a critical indicator of soil quality (Rasiah et al., 1997). In the overoiled Meota loamy sand, major soil physical properties such as stability of dry and wet aggregates, bulk density and hydraulic conductivity were markedly improved within four months and soil microbial population within three months of incorporating the well rotted manure (Table 3). In the unfertilized plots, manuring effected a 20% reduction of the erodible soil fraction, a 30% increase in mean size of waterstable aggregates, a 20% decrease in bulk density, 56% increase in potential rate of water movement and a 131% increase in the number of live bacteria.

Our results tend to agree with studies on artificially eroded soils in that plots receiving manure have more waterstable aggregates than in check plots (Dormaar et al., 1988) and that the beneficial effects of manure in restoring soil productivity are much larger than those achieved with inorganic fertilizers (Larney and Janzen 1996). However, our soil analyses (Table 3) also indicate that the effectiveness of manure in improving soil conditions for plant growth generally decreased with increasing rates of previous fertilizations. This decrease can be attributed to the large total amounts of inorganic nutrients applied in two consecutive fertilizations (i.e. 900 kg N + 206 kg P_2O_5 + 144 kg S/ha in all F4 plots and half that in F2 plots) and to the length of time by which the fertilizations preceded the manure application (i.e. 31 and 13 months). Evidently these fertilizations provided sufficient nutrients to stimulate soil microbial growth and accelerate oil decomposition and and they also allowed plenty of time and created favorable conditions for the bioconversion of hydrocarbons into stable, soil structure-improving, humus.

When manure is applied to unfertilized, oil-contaminated soil it will not only improve soil structure but will serve as a slow release source of various macro-and micronutrients for oil decomposing microbes and for crop growth. Thus the extent of reclamation effected with manure following an oil spill on farmland depends not only on the amount but also the type of manure being applied. In

Table 3. Effect of manure application in spring 1989 on selected surface soil properties in a heavy oil-polluted Meota loamy sand when sampled 4 months later.

Oil (O) and Fertilizer (F) treatment	Erodible Fraction†, %		Size of Waterstable Aggregates, GMD, mm‡		Bulk Density, g/cm^3		Hydraulic Conductivity, cmH_2O/hr		Bacterial Population, no. x 10^6/g soil§	
	unmanured	manured	unmanured	manured	unmanured	manured	unmanured	manured	unmanured	manured
01F0	59.1	48.1	3.62	4.69	1.25	1.01	6.87	10.75	268	618
01F2	65.8	55.2	3.98	4.69	1.23	1.08	8.57	12.55	191	536
01F4	59.4	59.5	4.71	4.87	1.16	0.98	5.08	15.52	277	438
Average	61.4	54.3	4.10	4.75	1.21	1.02	6.84	12.94	245	531

† The fraction of soil susceptible to erosion by wind, i.e. aggregates <0.84 mm in size, was determined by rotary dry sieving.

‡ Waterstable aggregates were determined by wet sieving and aggregate size distribution was expressed as the geometric mean diameter (GMD)

§ Bacteria enumerated by dilution plating on Soil Extract Agar of samples collected August 9, 1989; while physical properties were determined on samples collected September 19 and 20, 1989.

reclamation studies at the University of Alberta (Toogood 1977) application of 9 t/ha of a cattle manure with low nutrient content failed to increase the yield of oats growing on oil-polluted soil in the greenhouse while addition of 12 t/ha of a N-rich chicken manure to soil from a spill site significantly increased microbial CO_2 production when incubated in the laboratory. In our field study at Maidstone, SK a single manure application was very effective in improving soil structure and productivity (Tables 3, 4 and 5) because well rotted manure was used at a rate of 20 t organic matter/ha which is similar to the manuring rates used by Dormaar et al. (1988) and by Larney and Janzen (1996) to successfully restore productivity in artificially eroded soils.

Effect of Manure on Cereal Production

Based on the results from our earlier greenhouse and field tests for the tolerance of various crops to residual oil we decided to plant the two most tolerant cereals, viz. oat and wheat, into the 'overoiled' plots in spring 1990, i.e. one year after the manure application. Unfortunately, all plants had already suffered significant damage from predation by grasshoppers when both cereals were sampled at flowering stage, in late July. Yet the beneficial influence of manuring on emergence and vegetative growth could still be measured and was very evident according to the data in Table 4. In the unfertilized plots the manure treatment effected a 53% increase in plant density and a 150% increase in DM production of oats; the corresponding increases by wheat were 55% for stand density and 65% for biomass production. The effectiveness of the manure in improving cereal growth tended to decrease with increasing rates of previous fertilization (Table 4), i.e. the same trend as observed earlier for manure effects on soil properties that are critical for plant development (cf. Table 3). However, even in fertilized plots the benefits of manuring were still strong. When averaged across all fertilizer treatments oats in overoiled, but manured plots had essentially the same plant density as in unoiled plots (218 vs 214) and produced only 29% less biomass (146 g/m^2 vs 206 g/m^2). For wheat too plant density in manured plots was very similar to that in unoiled soil (177 vs 185) while DM production was only 12% less (98 g/m^2 vs 112 g/m^2). These comparisons with unoiled controls emphasize how effective a single manure application can be in restoring full crop productivity to a severely oil-polluted soil. Chemical analyses of the plant material indicated similar N contents on manured and unmanured plots, but P contents were consistently greater in cereal biomass from manured plots (data not shown). These increased plant P contents are corroborated by studies with eroded soil which have attributed part of the restorative ability of manures to improvements in the soil's P-supplying power (Dormaar et al., 1988; Larney and Janzen 1996).

In 1991, when oats were grown to maturity, the influence from the single manure application, two years earlier, on crop production in the oil-polluted soil was again highly beneficial. When averaged across fertilizer treatments manuring resulted in a 55% increase in plant density, a 70% increase in crop biomass and an 82% increase in grain yield relative to the unmanured plots (Table 5). However, in contrast to the results obtained in 1990, there was a significant positive interaction between manuring and earlier fertilizations in enhancing crop growth and particularly grain yield. It may be that the initial crop response to manuring of oil-polluted soil is affected primarily by the improvement in soil physical properties while subsequent crops will depend

increasingly on fertilization to produce optimum yields under the improved soil conditions. This corroborates the suggestion made by McGill during earlier oil spill studies (cf. Toogood 1977) that manure should
always be used in conjunction with other fertilizers. On the manured, unfertilized plots plant density

Table 4. Effect of amendment with manure on plant density and dry matter production of two cereals at flowering (July 26) in 1990 on heavy oil-polluted Meota loamy sand.

Cereal type	Oil (O) and Fertilizer (F) treatment	Plant Density, plants/m^2		Aboveground Dry Matter, g/m^2	
		unmanured	manured	unmanured	manured
Oat	01F0[†]	179	273	60	150
Oat	01F2	148	169	93	117
Oat	01F4	137	211	77	172
Oat	Average	155	218	77	146
Wheat	01F0[†]	132	204	66	109
Wheat	01F2	164	181	76	99
Wheat	01F4	123	146	41	85
Wheat	Average	140	177	61	98

§ Average plant density and DM on corresponding unoiled, unfertilized and unmanured, i.e. 00F0, plots was 214 plants/m^2 and 206 g/m^2 for oats; and 185 plants/m^2 and 112 g/m^2 for wheat.

was identical, biomass production was 8% more and grain yield was 32% higher than on the corresponding unoiled and unmanured plots (Table 5). This comparison proves that a single manure application was able to fully restore, within two years of soil amendment, the productivity for cereal grains on the oil-polluted Meota loamy sand. In a study of organic amendments to restore soil productivity of oil well sites in central Alberta (Akinremi et al., 1999) composted cattle manure was superior to alfalfa hay, fresh cattle manure and wheat straw and was able to restore wheat yields within two years of soil incorporation. Our results also agree with studies on artificially eroded soils in southern Alberta which found that treatment with manures or manure plus fertilizer combinations

Table 5. Effect of amendment with manure on plant density and production of oats at maturity (August 26) in 1991 on heavy oil-polluted Meota loamy sand.

Oil (O) and Fertilizer (F)	Plant Density, plants/m^2	Aboveground Plant Dry Matter, kg/ha	Grain Yield, kg/ha

	unmanured	manured	unmanured	manured	unmanured	manured
01F0†	178	240	5571	7428	2524	3715
01F2	98	229	3753	8487	1642	3961
01F4	126	156	4870	8135	2206	3925
Average	134	208	4731	8017	2124	3867

† Average plant density and production of oats on the corresponding unoiled, unfertilized and unmanured, i.e. 00F0, plots was 240 plants/m^2, 6865 kg DM/ha and 2824 kg Grain/ha.

essentially restored productivity within one or two years as measured by wheat yields (Dormaar et al., 1988; Larney and Janzen 1996). The effect of these soil amendments on grain quality had not been examined in the Alberta studies thus we analyzed the harvested oat grain for several quality characteristics. On previously fertilized plots there was no significant difference in protein content, kernel size and test weight between grain from manured and from unmanured treatments (data not shown). However on unfertilized plots manuring lowered the protein content by 9%, although the total quantity of grain protein harvested per unit area was still markedly increased with the 47% increase in grain yield (cf. Table 5), and manuring did increase the kernel mass by a remarkable 59% and the test weight by 86% over that of grain from the unmanured check (data not shown).

These field study results lead us to conclude that amendment of the oil-polluted soil with a single application of old manure was highly effective in improving critical soil properties and in restoring soil productivity not only in terms of grain yield but also with regard to grain quality.

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Phytoremediation as an *In-Situ* Technique for the Restoration of Oil-Contaminated Sites*

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Phytoremediation is the use of plants and their associated microorganisms for the *in situ* (or on-site) treatment of contaminated soils. Based on a review of relevant literature, we have concluded that phytoremediation is a steadily emerging technology with the potential to facilitate the cleanup of petroleum hydrocarbons at oil-contaminated sites. Initial indications are that phytoremediation is effective at degrading and containing petroleum hydrocarbons in soil as well as transferring these compounds from soil to the atmosphere (Cunningham *et al.*, 1996; Siciliano and Germida, 1998; Sims and Overcash, 1983). The literature suggests that the degradation of petroleum hydrocarbons by microorganisms in the rhizosphere of plants is the primary loss mechanism for these compounds (Gunther *et al.*, 1996; Jordahl *et al.*, 1997; Radwan *et al.*,1998).

Successful trials have involved a variety of plants, but the majority of research has focused on grass and legume species (Aprill and Sims, 1990; Qiu *et al.*, 1997; Gunther *et al.*, 1996; and Reilley *et al.*, 1996). In fact, a number of legumes have been found to grow naturally in oil-contaminated areas (Gudin and Syratt, 1975). Our preliminary screenings indicate that several plants native to the Prairie and Boreal Plain Ecozones of Western Canada, as well as several introduced species, may be useful in phytoremediation efforts within these areas.

The effectiveness of phytoremediation is site-specific in that it can be greatly affected by environmental conditions. Phytoremediation is facilitated by adequate quantities of nutrients, water and oxygen and is enhanced at warmer temperatures (Wright *et al.*, 1997). Phytoremediation potential may be restricted in soils with abundant organic matter or clay – soil components that tend to reduce the bioavailability of petroleum hydrocarbons (Otten *et al.*, 1997; Cunningham *et al.*, 1996). It may also be inhibited if contaminant concentrations are too high or too low (Committee on *In Situ* Bioremediation *et al.*, 1993; Hrudey and Pollard, 1993; Rogers *et al.*, 1996; Atlas and Bartha, 1998).

Certain petroleum hydrocarbons are easier to phytoremediate than others. In general, BTEX compounds are relatively easy to remediate because they are (i) rapidly degraded in the presence of oxygen; (ii) relatively soluble, thus making them bioavailable; and (iii) can serve as the primary electron donor for many bacteria widely distributed in nature (Committee on *In Situ* Bioremediation *et al.*, 1993). Large and lipophilic compounds such as the four and five-ring PAHs are more difficult, though not impossible, to remediate. The remediation of these compounds is more difficult because of their limited

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bioavailability, which is a result of their adsorption to soil organic matter and clay, as well as their limited ability to pass through cellular membranes of plants and microbes (Cookson, 1995). Nevertheless, cometabolism by microorganisms has been shown to result in the degradation of some large PAHs, such as benzo[*a*]pyrene (Kanaly *et al.*, 1997). In general, weathering processes selectively reduce the concentration of easily-degradable contaminants, making older sites more difficult to phytoremediate than newer sites (Bossert and Bartha, 1984; Cunningham *et al.*, 1996).

The three major alternatives to phytoremediation are natural attenuation, engineering, and bioremediation. Limited information suggests that phytoremediation is slightly less expensive than bioremediation and can be orders of magnitude less expensive than some of the more costly engineering techniques (Cunningham *et al.*, 1996; Cunningham *et al.*, 1995, Tsao, 1999; Bollag *et al.*, 1994). It is faster than natural attenuation, but typically slower than engineering and bioremediation. Because phytoremediation is an *in situ* technique, it is less disruptive compared to the excavation efforts required in *ex situ* engineering and bioremediation. Phytoremediation is most likely to have the greatest effectiveness with shallow contamination, which is co-incidental with the greatest root density. A variety of remediation approaches may be required to accomplish all reclamation goals at a contaminated site (Hrudey and Pollard, 1993). The type of approach or approaches chosen will most likely be site-specific and depend on the desired speed of reclamation as well as the number of dollars dedicated to the reclamation effort.

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1996). There is a single large toroidal vortex created, i.e. like a donut shaped tornado, which is driven by a surface layer traveling radially outward from the pond mill. The surface velocity remains quite high even at large distances from the pond mill. The reason for this phenomenon is that upwelling is present over most of the pond, e.g. between the pond mill and the vortex center located close to shore (J. D. Bugg, 1996). The oxygen transfer rate of the Little River Pond Mill® was found to be 1.47 g O_2/W h with an average wind speed of 5.33 m s^{-1} which is comparable with the oxygen transfer rate of other low speed surface aerators (C. Ruiu et al. 1997). It should be noted that the results of this test are skewed to the negative due to the deoxygenation chemical used. The chemical used has a higher efficiency rating under circulating conditions which was not taken into consideration when the quantity of chemical was added. We are presently setting up an experiment using nitrogen gas as the deoxygenation agent since it does not have a residual effect under circulating conditions.

4.0 Research Results

4.1 Flow

4.1.1 In a 4 m x 15 m pond, with a 6.71 m s^{-1} wind, a single, large, toroidal vortex of 9 m^3 s^{-1} is created. (J. D. Bugg, 1996)

4.2 Oxygen Transfer Rate

4.2.1 OTR = 1.47 g O_2/W h with an average wind speed of 5.33 m s^{-1}. This is comparable with the oxygen transfer rates of other low speed surface aerators. (C. Ruiu et. al., 1998)

4.3 Biological Oxygen Demand

4.3.1 Reduction of effluent vs. influent - Omemee Sewage Lagoon, Omemee, ON, 1991

% Reduction	Influent	Effluent
89.8 - 99.8 %	167 mg/L	1.1 mg/L

4.3.2 August 1998, Municipality of Val Barrette, QB: < 5.0 mg/L; maximum allowable limit is 25 mg/L summer, and 30 mg/L winter. Initial values were not provided therefore a comparison cannot be made; information provided can only be used as an indicator Eco-Guide Environnement, Lachute, QB

4.4 Dissolved Oxygen

4.4.1 Pond mills installed on sewage lagoons, Village of Milligan , Nebraska, USA, May 25, 1995

Date	Dissolved Oxygen
25-05-95	2.3 ppm @ 3 feet
29-07-95	8.9 ppm @ 3 feet

4.4.2 Pond mills installed on Pointe Calumet Lake, QB, June 06, 1997 - Super Aqua Club

Average values of Pointe Calumet Lake on June 06, 1997

	Depth (meters)						
	0	1	2	3	3.5	4	4.3
Temp (° C)	21	21	20	17.5	16	16	15
0_2 (mg/l)	11	11.2	11.2	10.5	10.3	10.2	2.6

Site 1 and 2 combined - Pointe Calumet Lake average values on August 07, 1997

	Depth (meters)						
	0	1	2	3	3.5	4	4.3
Temp (° C)	23	23	2.75	22.5	22.5	22.25	22.25
0_2 (mg/l)	9.3	9.3	9.3	9.3	9.8	8.4	7.7

A mixing of the lake has altered the supersaturation oxygen values at the surface and facultative to anaerobic conditions near the bottom, observed on June 06, 1998, and created an even temperature and oxygen profile throughout. This enables indigenous organisms to compete more efficiently thereby increasing the natural diversity of the lake.
Eco-Guide Environnement, Lachute, QB, 1997

4.5 Microbial Action

4.5.1 Fecal coliform reduction of Pointe Calumet Lake, QB (recreational urban lake with water slide). Prior to pond mill installation: 300 cfu/100 ml, after pond mill installation: < 2 cfu/100 ml
Eco-Guide Environnement, Lachute, QB, 1997-98

4.6 Ammonia (NH_3)

4.6.1 Major hog processor in USA; processes 16,000 head of hogs with 2 million gallons of waste water, daily; 18 pond mills installed on intermediate, 30 surface acre (5 foot depth), aerated lagoon (which had the required number of 200 hp aerators in operation). It was found that the aerators (located on a 4 surface acre leg of the primary lagoon) were not operating efficiently and maintenance was extremely expensive. The finishing lagoon, 30 acres with a 3 foot depth, had 6 mills installed.

Intermediate lagoon

18-05-95 (prior to installation)	24-07-95 (60 days after installation)
110-120 ppm	55-60 ppm

Excel Corporation, 1996

4.7 Suspended Solids

4.7.1 Reduction of effluent vs. influent - Omemee Sewage Lagoon, Omemee, ON 1991

% Reduction	Influent	Effluent
89.2 - 99.8 %	240 mg/L	0.5 mg/L

4.8 Odor Potential (ou/L)

4.8.1 control = 226,237 ou/L; test = 97,819 ou/L

ou = odor units
(Michael R. Toombs, 1997)

4.9 Total Phenols
4.9.1 control = 3.06 mg/L; test = 0.25 mg/L
(Michael R. Toombs, 1997)

4.10 Total Volatile Fatty Acids (VFA's)
4.10.1 control = 6904 mg/L; test = 113 mg/L
VFA's below 230 mg/L correspond to a liquid manure without offensive odors
(Michael R. Toombs, 1997)

5.0 Conclusions

The circulation action, combined with the passive and active aeration promoted by the pond mill, favors a more complete decomposition of organic matter, mineralization of nutrients, and an overall change in the population dynamics of the body of water thereby creating an environment which is more diverse and verging on equilibrium. Within this system the byproducts of respiration of one organism are utilized by another organism, on down the line, ensuring a complete nutrient and carbon cycling and very efficient, and inexpensive, remediation process.

The benefits of the bioremediation can be seen in such parameters as:
1) reduction of odors and toxic respiration byproducts by moving away from the anaerobic processes which produce those substances. By reducing or eliminating toxic gases, reductions in mid or late winter fish kills are possible, as well as increases in vertebrate, non-vertebrate, and microbial diversity. Recreational use of lakes could also become more pleasant.
2) reduction in factors such as BOD, SS, phenols, VFA's, and increases in DO and organism populations diversity of the water can improve both the image and the functionality of the body of water.

The environmentally friendly remediation of surface water supplies, waste water, and liquid sewage, through use of Little River Pond Mill®, a bioremediation facilitator, provides environmental, economic, and social benefits to the environment, the commercial animal producer, and the surrounding community. It can reduce environmental, economic, and social costs associated with surface water, waste water, and liquid manure management.

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Native Prairie Revegetation On Wellsites In Southeastern Alberta*

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1.0 Introduction

Native grassland ecosystems in southeastern Alberta are presently under pressure from cultivation, invasion by non-native species and industrial development. Oil wellsite construction is one example of such pressure. Mitigating the impacts of wellsite construction is in the interest of conservationists, industry and livestock producers. Wellsite construction typically includes salvage of surface soil separately from subsoil. While the seed bank and some root propagules are retained through these salvaging practices, the pre-disturbance structure and composition of the native plant community is lost. Following site abandonment, current revegetation practices primarily consist of seeding with native wheatgrass cultivars. These practices represent great changes over typical industry standards just ten years ago when crested wheatgrass (a non-native/introduced species) was used. Nonetheless, the lack of scientific evidence concerning the effectiveness of these techniques and continued interest in alternative techniques presented a need for research.

The Native Prairie Revegetation Research Project (NPRRP) was initiated by members of industry, government and the research community to address some of the outstanding concerns about wellsite revegetation on native grassland. Two objectives were identified: 1) Determine the impact of alternative seeding treatments on soil and vegetation and 2) Produce a quantifiable description of what constitutes successful revegetation of native prairie sites.

The approach of this study was to apply ecological principles to solve practical problems. In essence the key is to answer "*So what?*". Results reported must be interpreted in a context which makes them useful for making management decisions. To integrate the scientific results of this study within an interpretable framework it was necessary to devise a single definition for revegetation success. Traditionally revegetation success has been defined by one of many distinct management goals such as land capability or productivity. For the purpose of interpreting the results of this study it was decided to define all revegetation success within the context of complete restoration (return of the site to the undisturbed state). From this perspective, other revegetation goals simply constitute incomplete restoration. Insofar as management is as much art as science, the goal of this study was to present results which may serve as underlying principles of management rather than create recipe book solutions.

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The body of ecological knowledge about grasslands contains some powerful tools for studying revegetation. Change in vegetation over time, known as succession, is a well-established process. Typically the expected change in vegetation over time is annual weeds followed by early successional grasses followed by late successional grasses. As revegetation efforts move closer to establishing the late successional communities revegetation success can be considered greater. The degree to which various treatments resemble late successional communities can be determined by comparing them to the undisturbed control.

2.0 Methods

For the dry mixed-grass prairie subregion portion of the NPRRP four wellsites on Chernozemic
soil and three on Solonetzic soil were selected for study. Each site was comprised of four revegetation treatments and an undisturbed control. Revegetation treatments included: Natural Recovery- no seeding, Current Mix- seed mix dominated by native wheatgrass cultivars, Simple Mix - seed mix with wheatgrasses plus other native grasses, Diverse Mix- wheatgrasses, other grasses and thirteen perennial forbs. Each of these revegetation treatments represents respectively higher cost and effort. Plant communities were monitored for biomass production, species richness, species composition and importance value (a combination of density, frequency, canopy cover and basal cover) of various functional groups (groups of similar species). Soil characteristics such as available nitrogen were monitored to determine treatment effect.

3.0 Results and Discussion

Total biomass was largest in the control, intermediate in the seeded treatments and lowest in the natural recovery. Species diversity was lowest in the current treatment and highest in the diverse treatment due to the presence of a perennial forbs. Similarity indices indicated that the diverse and simple treatments were most similar to the control in species composition. An important observation was that many of the perennial forbs planted in the diverse treatment were not in the control and so did not increase community similarity. Available soil nitrogen was highest in the natural recovery treatment, intermediate in the seeded treatments and lowest in the control.

The community similarity results can be explained by looking at the importance values of various functional groups. All seeded treatments had high importance values for wheatgrasses. Perennial non-wheatgrasses had low importance values in the seeded treatments but higher importance in the Control treatment. Perennial non-wheatgrasses seemed to be increasing in importance in the natural recovery treatment although this treatment is still dominated by annual forbs after 3 years. Dominance by wheatgrasses in the seeded treatments resulted in communities which were significantly different from the Control and Natural Recovery communities. It is likely that the wheatgrasses inhibited the establishment of other grasses.

The results reported above can be interpreted in terms of our understanding of grassland succession. The natural recovery treatment represents an early successional community with a high importance of annual forbs and high resource availability. The undisturbed control represents a late successional community with high biomass and low resource availability. The seeded treatments represent a closed community where succession may have been halted by the dominance of wheatgrasses.

Based on the above results the following management recommendations can be made: 1) Cultivars of western, northern and slender wheatgrass should not be mixed with needle and thread, June and blue grama grass. 2) Perennial Forbs and diverse seed mixes should only be used if clear goals are identified such as increasing similarity to undisturbed communities 3) natural recovery can be effective in areas of low erosion risk, small disturbances and where a long time frame of recovery is acceptable.

Vegetation Characteristics On A Pipeline Right-Of-Way Twelve Years After Construction In Southern Alberta*

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1. Introduction

Gas pipelines cross much of Alberta, many of them constructed on native grasslands where establishment and persistence of acceptable vegetation can be a challenge due to soil characteristics, disturbance effects, climate and grazing. Re-establishment of native plant species is becoming more important in reclamation as a resource for wildlife and domestic animals. Often disturbances are seeded with non-native species with different palatability, productivity, competitive ability and longevity. These differences can make reclamation of a pipeline right-of-way (RoW) and management of the native range adjacent the RoW more difficult.

In 1986, a long-term project was initiated by NOVA Corporation of Alberta to monitor revegetation on native rangelands in southeastern and southwestern Alberta. Two pipeline laterals, that crossed 5 ecoregions, were selected and four sites were established on each lateral. Construction and revegetation of the Milo lateral, which crosses the Dry Mixed and Mixed Grass Ecoregions, occurred in 1986; construction of the Porcupine Hills lateral, which traverses Aspen Parkland, Fescue Grassland and Montane Ecoregions, started in February, 1987. Revegetation was completed by the end of 1987. Both RoWs are 18 m wide. Topsoil was conserved using ditchline stripping with the stripped soil stockpiled on the work side of the RoW. Vegetation assessments were made annually for the first five years after reclamation and again in 1998.

2. Methods

Experimental design is a strip-plot. A grazing exclosure, varying from 0.25 to 0.90 ha, was built at each site. Each grazed and ungrazed strip-plot was further divided into work, trench, spoil and undisturbed RoW zones. The Milo and Porcupine Hills RoWs were seeded to different native seed mixes that were available at time of revegetation.

In 1998, species composition was determined using 30 m permanent transects established in 1986 and 1987. Ten, 0.10 m^2 quadrats per transect were assessed in each treatment. Each species rooted in the quadrat was identified. Density and relative % biovolume of each species was recorded. Relative % biovolume is the volume that each plant contributes to the total volume of vegetation found in the quadrat. Sampling was done twice during the growing season, in June and August, to accurately assess both early and late season plants. Ground cover, which was divided into live, dead (which included

* Presented at the 24th Annual Meeting of the Canadian Land Reclamation Association held jointly with the Saskatchewan Environmental Industry and Managers Association, Saskatoon, Saskatchewan, September 28-30, 1999.

manure) and bare ground, was visually assessed using 0.1 m^2 quadrats. Ten measurements were taken in each treatment in June, 1998.

The Milo and Porcupine Hills sites were analyzed separately. June data were used for forb analysis, since identification was more precise at this time. August data were used for grass analysis since most of the grasses were in flower during the second assessment. Grass species were grouped as total, native, introduced, rhizomatous and tufted. Forbs were grouped into total, leguminous, native, introduced, annual and perennial.

3. Results

Grazing impacted the amount of live, litter and bare ground cover. Grazing significantly increased bare ground cover on the trench at both Milo and Porcupine Hills. For Milo, there were significant differences between grazed and ungrazed treatments in both spoil and work, but not undisturbed zones; whereas in the Porcupine Hills, there was little difference between grazed and ungrazed treatments in the spoil, work or undisturbed zones. In Milo, grazing had little impact on live ground cover in the spoil, trench, work or undisturbed zones, while in Porcupine Hills, grazing significantly reduced live cover in all four zones. Grazing also reduced litter in the RoW zones on both laterals.

At Milo, grazing and RoW zone did not significantly affect forb biovolume or density. However, there were differences among RoW zones, with the spoil having higher biovolume (for total, introduced and perennial forbs) than either trench, work or undisturbed zones. Trench had the lowest total forb biovolume. At Milo, work and undisturbed zones had higher biovolumes of native and tufted grasses than spoil and trench zones. The trench had the highest biovolume of introduced and rhizomatous grasses. Grazing did not significantly affect the biovolume of any of the measured grass variables, but it significantly increased the density of total grass and native grass. Grazing increased the density of rhizomatous grasses in the spoil and trench zones, whereas it decreased density in the work zone. Grazing decreased the number of tufted grasses in the spoil and trench zones, while it increased density in the work and undisturbed zones.

At Porcupine Hills, grazing increased density of legumes in the trench and work, but had no effect in the undisturbed zone and decreased density in the spoil zone. Legume density was highest in the grazed trench. Grazing also increased the density of introduced forbs in the spoil, trench and work zones, but did not affect density in the undisturbed prairie. Grazing decreased all forb biovolumes except introduced forbs, which increased with grazing. Forb biovolumes that decreased with grazing did not have a corresponding decrease in plant density. Grazing significantly increased total grass and tufted grass biovolume but did not affect grass density. RoW zone did not affect measured grass variables. Grazing increased biovolume of native grasses on the spoil, trench and work zones, but did not affect undisturbed prairie. Grazing did cause a substantial increase in introduced grass in the undisturbed zone.

4. Summary

Twelve years after pipeline construction, grazing appeared to have little impact on the biovolume or density of forbs in either Milo or the Porcupine Hills. Grazing did impact grasses, although there was no consistency between Milo and Porcupine Hills as to which variables were affected and how. RoW zone effect was most notable in the Milo grass variables, whereas, zone did not affect grass biovolume or density in the Porcupine Hills. Because of inherent differences between the laterals (and even the sites themselves) it is important to interpret these results carefully, keeping in mind lateral differences such as climate, soils and species.

Bioengineering And Reclamation To Stabilize A Lakeshore Slope*

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1.0 Introduction

There is little published scientific documentation on transplanting vegetation for slope stabilization in the Canadian Aspen Parkland. Limited published information and general practice garnered from anecdotal evidence suggest transplanting is most successful when plants are dormant. In the Aspen Parkland this corresponds to early spring (April, May) prior to new growth occurring or when plants are either dormant or are approaching dormancy after mid October. However, transplanting during these periods may be inopportune due to inaccessible, muddy sites in spring or frozen soil conditions in fall. Successful transplanting during nondormant stages would allow an increased time frame using this reclamation method.

Transplanting appropriate native vegetation to barren sites from local areas having similar biotic and edaphic conditions can introduce an adapted vegetation cover with genetic variation which requires little if any maintenance and integrates well with the surrounding vegetation. Providing a more hospitable growing environment by combining transplanted vegetation with stable moisture retaining soils and initially providing nutrients may expedite succession toward mid seral stages which in turn can encourage soil stabilisation by reducing soil erosion and anchoring the soil in place via plant root establishment. This revegetation method may reduce the effects of soil instability and add soil nutrients such as nitrogen by nitrogen fixing plants in a much shorter time period than when attempting to establish the same plant community by seeding. Seeds from most native forbs, grasses and shrubs are currently seldom commercially available. Incorporating a bioengineering technique such as terracing with transplanting can potentially increase slope stabilization. Terracing can reduce soil erosion by slowing and collecting surface runoff while providing an environment conducive to plant growth. Bench terraces virtually eliminate the effect of slope caused erosion thereby allowing nutrients to remain in situ without being transported to lower slope positions.

2.0 Site Description

The severely degraded lakeshore slope is located in Elk Island National Park, Alberta. This site, approximately 60 m long by 13 m high is situated on a west facing, sparsely vegetated, steep, eroded slope located above Astotin Lake and has been eroding for at least 30 years. It is situated on predominantly Orthic Gray and Dark Gray Luvisolic soils and consists of 3 gullies and 3 slopes eroded to the C horizon. Portions of the upper slopes are vertical, naturally devoid of vegetation and continually exfoliating and

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slumping soil due to water erosion. The sparsely vegetated, less steep sections vary in inclination between 28 and 38 degrees.

3.0 Methods

The 28 to 38 degree slopes were initially terraced to provide a level growing area. A spent mushroom compost amendment (25% by volume) was added to the worked (20 cm deep) C horizon to increase soil organic matter, soil nutrient content and improve water retention capability.

During the first two weeks of August 1997, vegetation islands approximately 20 cm in diameter and 10 to 20 cm deep were removed by shovel from previously chosen donor sites within 2 kms of the terraced site and transplanted. The chosen donor areas predominantly contained native shrubs, forbs and grasses. An estimated 30 to 50% of the vegetation was either in bloom or fruiting when removed in the nondormant state. Daytime ambient air temperatures on the slope varied from 27 to 32 °C during the nondormant transplanting time.

Dormant transplanting was initiated October 13, 1997. Morning temperatures were -6 °C with day time highs of 6 °C. The terraced slope soil was frozen in isolated small areas (approximately 1 m long) up to 4 cm deep making transplanting conditions difficult. All vegetation on the donor area was considered dormant with no sign of green nondormant foliage; all leaves were either coloured or desiccated and fallen.

In June and August 1998 all plant species within the vegetation islands (average size 0.3 m2) were identified and counted. Overall vegetation island vigour was categorised into 3 classes. Percent mortality of vegetation in each island was determined as the percent vegetation that appeared dead expressed as a percent of the total visible vegetation. The quantity of islands were then categorised into seven arbitrary mortality categories.

4.0 Results

There was a significant difference in mortality between dormant and nondormant 20 cm diameter vegetation islands transplanted. Nondormant islands had significantly lower vegetation mortality (10% or less) than did dormant islands on both slopes and gullies. Initially in June, slopes had significantly more islands with 10% or less vegetation mortality than did gullies. However, by August there was no significant difference in island vegetation mortalities between gullies and slopes.

Vigour was significantly greater in June than August, with more vigorous (healthy appearing) plants on nondormant islands. However, by August there was no significant difference between dormant and nondormant transplants. There was a high percentage of both healthy dormant and nondormant islands. There were significantly more healthy, vigorous islands on slopes compared to gullies throughout the study. Species diversity

increased between June and August 1998. During this time only grass and sedge species density increased while forb and shrub/tree species densities diminished in all situations.

5.0 Conclusion

The results from this study provide evidence that transplanting nondormant vegetation islands on a terraced Aspen Parkland site is successful in establishing plant communities and can provide an essential component when reclaiming a relatively barren site.

If these results are repeatable on a broader scale, reclamation using vegetation islands could proceed throughout the growing season rather than be restricted to early spring and late autumn when working conditions are often less than ideal.

The Evolving Native Plant Industry in Saskatchewan*

Nora Stewart and Andy Hammermeister, Native Plant Society of Saskatchewan

When the pioneers began to settle the prairies they might have viewed the task of plowing the land as "reclaiming" by the dictionary definition of "make available for human use by changing natural conditions". Later, especially after the drought years, reclamation meant getting something to grow, usually introduced grasses. Now, because of appreciation of our prairie plant species, reclamation may mean replacing native with native. This change has created a demand for native seed which in turn has propelled the native plant industry.

The change can be seen in policy development in both government and non-government agencies. Ducks Unlimited Canada started working with native plants in the 1980s as they embarked on reclaiming agricultural land for nesting cover. In 1992 Chris Nykoluk of PFRA was able to get management there to agree that native pasture should be reclaimed with native plants. It is interesting that, Saskatchewan Agriculture and Food's Guidelines and Procedures for Developers is entitled "Restoration of Saskatchewan's Agricultural Crown Rangelands. This clearly indicates the desire to return the land to its former state There are many other examples to support this trend.

A milestone for native plants which has had a major impact on the industry was the formation of the Native Plant Society of Saskatchewan. A meeting to assess the interest in such an organization was held in September 1994 and the first annual meeting of the Society took place in January 1996. The Society, along with the Northwest Saskatchewan Grasslands Association commissioned a study which resulted in the publication in January 1997 of the "Market Assessment of Native Plant Materials in Saskatchewan". This useful pamphlet acts as a benchmark listing suppliers and buyers of native plant materials as well as issues in the marketplace. Some problems identified include extreme secrecy, lack of knowledge on the part of buyers and unpredictability of the economic conditions in the province. High cost and low availability of seed were the major factors against the use of native species. One source, however, said there was "no need to produce native plant materials because there is an unlimited supply of it in the province".

Considerable debate goes on as to what is best where native plants are required for a project. The options are cultivars including the standard mix (three wheatgrasses plus green needle grass) which are not always suited to our conditions, wild harvested seed which is often unpredictable, and seed produced in farm plots from wild-harvested material. About six years ago, Ducks Unlimited Canada, along with researchers, primarily at Agriculture Canada stations, started to develop ecovars by selecting plants from

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Canadian prairie stock and breeding them to maintain genetic diversity This seed is now in the multiplication stage and may be available to growers in the year 2001. About thirty species are anticipated, including grasses, forbs and shrubs. This will change the industry, allowing many more species to be readily included in seed mixes. It should. be noted however, that when our market assessment was done, a total of 22 grasses, 91 forbs and. 28 shrub and tree species were listed as being available through Saskatchewan suppliers. Which type of seed is most appropriate will. continue to he debated but there's no doubt that the demand for increased diversity will grow as seed becomes more available.

One new venture which will affect the industry in Saskatchewan is the development of the Native Plant Society web site and an associated listing service. The web site (www.npss.sk.ca) is due to be launched next month. The listing service will soon follow including buyers, sellers, experts and many sources of information.. In the last few years many books and even. some videos relating to reclamation. have come on the market. These include how-to manuals and plant identification books. Having these sources identified should make it easier for those getting started using native plants to gain the knowledge they need. It is hoped. that having seed data - amounts of various species available from different growers or harvesters, lab tests if any, maybe even price - accessible on the net may reduce the secrecy identified earlier in the industry It should also make it much easier to link buyers and sellers. At the moment, it is difficult to determine how many producers exist in the province. Only twenty nine were identified in the market assessment published in 1997 but a successful listing service should bring forward many more. it is anticipated that at least in the early stages, the service will be free to members of the Native Plant Society.

The Society, we hope, is, by its many activities, increasing awareness about native plants and the possibilities of the industry. We publish brochures and a quarterly newsletter, have workshops and an annual meeting/conference. Our display has been seen at many functions around the province this year Just having a place that people can call, fax, write or email is helping to disseminate information. Andy had a flood of requests about the methods and costs of stripping native grasses when the lush production of spear grass seed became evident early this sum liter.

The bonanza versus bust of different years' harvest is a constant concern for the industry. It means that neither availability nor price of seed are predictable. But as the number of producers increases the likelihood of someone having a particular species should rise, and farm-produced seed may be more predictable because irrigation becomes a possibility. It seeing likely that more people will be producing natives for a variety of reasons. Although the oil activity will eventually slow, the gas industry in the province should expand, government agencies arc likely to encourage more native perennials: for grazing and all wildlife agencies want to increase diversity. Stricter government regulations may bring about greater use of natives. Low maintenance and low water use requirements will mean more use of natives in. parks, golf courses and the horticulture industry. Even though more seed will be produced. the price will likely remain high because of these new users.

Assuming that there will be more producers/harvesters and more demand for diversity, supporting facilities and equipment will have to be created. There will be more demand for seed cleaning and lab testing if people are growing small amounts of seed of a large number of species, it's not economical for them to have each tested, so other methods of ensuring a quality product may have to be devised. For example, some organizations of organic growers have their own inspection systems. Another need is for small-scale equipment for harvesting and processing the myriad of seed heads which are found on the wide variety of native grasses, flowers and shrubs.

In January 1997 the native plant industry in Saskatchewan was described as fledgling, immature and exciting. These descriptions are still appropriate but a lot has happened since then and the evolution will likely continue at the same pace.

Revegetation of Wellsite Disturbances on Fescue Prairie in East-Central Alberta. [*]**Add Figures

by

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Introduction

Past methods of revegetating disturbed land in Alberta, using a limited number of commercially-available species, have resulted in a net loss of biodiversity. Many commercial forage species are highly competitive and their use in the past have not allowed original prairie species to return to reclaimed sites. In some cases, these forage species have migrated from reclaimed areas and invaded the surrounding native prairie. Smooth brome grass, alfalfa, crested wheatgrass, Kentucky bluegrass, and Canada bluegrass are all considered invasive plants of natural habitats (White et al. 1995). Alteration of the plant community from native mixed prairie to crested wheatgrass or Russian wildrye has been found to significantly reduce soil quality (Dormaar et al. 1995). The use of these forage species in reclamation has resulted in landscape fragmentation incompatible with land-use objectives on rangelands or in conservation areas. At present, these species are not recommended and most wellsites located on native prairie are revegetated with a limited mix of available native grass cultivars. However, species diversity and compatibility of reclaimed areas with the surrounding native vegetation has not appreciably increased with the use of this species mix. Problems associated with disturbances of native prairie have been compounded by a poor understanding of grassland ecosystem processes and practices used to recover them. As a result, industry and government have indicated that improved methods of revegetation of wellsite disturbances and new guidelines for determining reclamation success were required. Most native plant species are less aggressive than forage species used in the past, however, their ability to facilitate recovery of native prairie on disturbed sites is unknown and requires documentation.

Project Goal

The goal of this project was to develop practical methods of revegetating wellsite disturbances on native prairie that will eventually return the site to sound ecological structure and function similar to that of the surrounding undisturbed prairie within an acceptable period of time. This five-year field study takes a revised look at what constitutes successful reclamation on abandoned wellsites.

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Practical means the method can be applied under operational conditions with good chances of success at reasonable cost.

Ecological Structure means the site will have soils and vegetation resembling that of native prairie but were not necessarily identical.

Ecological Function means maintaining the integrity of prairie ecosystem processes such as nutrient cycling, biomass production, etc.

Acceptable Period of Time means that other reclamation objectives will be taken into consideration including economic and social values.

Recovery of disturbed lands occurs through natural processes collectively referred to as ecological succession. In the past, land reclamation efforts have focused mainly on a single objective, ie. controlling soil erosion. This often resulted in reclaimed landscapes that were not compatible with the surrounding areas. Current changes in public perceptions have caused a corresponding change in reclamation objectives to include ecological considerations. Natural recovery processes act extremely slowly, often in excess of 10 years, and allow considerable potential for erosion to occur. Although erosion control is still of prime importance, current land reclamation efforts must also attempt to manipulate successional processes to accelerate recovery of these disturbed areas. Over time, reclaimed sites should blend with the surrounding undisturbed landscape both from an aesthetic and resource-use point of view.

Research approach

The Northern Fescue Prairie and the Dry Mixed Grass Prairie have been selected for study because of the volume of industrial activities occurring on them. The northern fescue grassland project was further broken down into sub-projects based on soil and plant community type: (1) mesic Chernozemic sites and (2) sandy sites.
Due to the new guidelines regarding minimum disturbance on native prairie, suitable full-scale disturbances were difficult to find. In the summer of 1997, three wellsites were selected within one of the sub-projects which focus on sandy sites.
Six sites were established (Figure 1) including three wellsites on mesic Chernozemic soils (1996) and three on sandy soil within the Dark Brown Soil zone (1997). Because the plant communities were very different on these two soil types, two studies were initiated in this sub-project. Five revegetation treatments were applied to each site representing varying degrees of species diversity and resemblance of the undisturbed plant community (Table 1).

Results

The soil stripping, storage, and replacement procedures used in the construction and reclamation of the well sites had few effects on soil parameters. The greatest effects due

to disturbance were an increase in available soil nitrogen, nitrification and increased microbial activity (data not shown). Re-assessment of soil parameters in year five of the study will evaluate the ability of treatments to ameliorate recovery of soil processes to pre-disturbance levels.

To gain an understanding of plant community dynamics on the revegetated sites, an index of relative importance for each species or species group was determined for each treatment and compared over two years. Importance values reflect how species or species groups dominated each treatment stand.

Mesic Chernozemic Sites

All seeded treatments established well in the year of seeding (1997). The importance of weeds was dramatically higher in the Natural Recovery treatment than on all the other treatments (Figure 2a). This result is not surprising considering that species planted in each of the seeded treatments were likely to compete for site resources (water, nutrients, light) and thus prevented weeds from establishing. Although the importance of weeds of all seeded treatments was higher than that of the Reference (undisturbed control), little difference in the importance of weeds was found among seeded treatments. This may reflect a similar degree of competitiveness among seeded treatments. In addition, the importance of native forbs was also higher in the Natural Recovery treatment equaling that found for the Reference (Figure 2b). As for weed species, the importance of native forbs on all seeded treatments were essentially the same. Importance of native forbs on all treatments was relatively high in comparison to the Reference. Surprisingly, results suggest that different seed treatments did little to impede native forb establishment but did hinder establishment of weeds. Importance of weeds or native forbs was not associated with importance of wheat grasses, the most competitive species group.

Rough fescue is the characteristic grass of the fescue grasslands. The same rate of rough fescue (pure live seed) was included in all seeded treatments. Results show that the importance of rough fescue was much lower than the importance of wheat grasses on all seeded treatments (Figure 2d). In addition, the importance of rough fescue appeared to be diminishing over time. The present findings are not entirely unexpected since rough fescue is a very slow growing species and other grass species were expected to grow faster and increase their cover and importance relative to rough fescue. However, the rate of decline in the importance of rough fescue does appear to be associated with importance of wheat grasses. The Reclamation treatment had highest importance of wheat grasses and the sharpest decline in the importance of rough fescue over the two years. The Simple treatments had the lowest importance of wheat grasses and least decline in the importance of rough fescue.

Sandy Sites Sites

Establishment for all seeded species was slow on sandy sites and many grasses, such as Indian rice grass only emerged in the second year after seeding (1998). The importance of weeds was higher in the Natural Recovery treatment than on all the other treatments (Figure 3a), however weed levels were high for all treatments compared with the Reference (undisturbed control). This reflected the low, overall establishment of seeded species on sandy sites allowing weedy species to establish within all seeded treatments. However, the importance of weeds appears to be sharply declining over time in the Reclamation treatment. In addition, the importance of native forbs was also higher in the Natural Recovery treatment equaling that found for the Reference (Figure 3b). Little difference was found in the importance of native forbs among seeded treatments.

Sand reed grass is an important species on sandy sites within Fescue Grasslands sub-region. The same rate of sand reed grass (pure live seed) was included in all seeded treatments. Results show that the importance of sand reed grass was only slightly lower than the importance of wheat grasses on all seeded treatments (Figure 3d). Importance of sand reed grass is increasing over time in the Simple treatment, which appears to be related to the importance of wheat grasses in 1998. The Simple treatments had the lowest importance of wheat grasses and greatest increase in the importance of sand reed grass.

Conclusions

Species composition on natural recovery areas were far less consistent and succession far less directed than for the seeded treatments. In this study, the natural recovery treatment was more variable within and especially among sites than the seeded treatments. In addition, weeds were more prevalent on natural recovery areas and few of the dominant grass species had established within three years.

Cross-seeding can be an effective method for reducing the effect of inter-specific competition on the species emergence. In this study, dominance based on importance values of the indicator species (rough fescue for the mesic sites and sand grass for the sandy sites) were similar across all seeded treatments. However, changes in dominance over time may occur in relation to other competitive species included in the seed mix.

Results to date indicate that native seed mixes have the potential for both effective site stabilization and establishing a more "ecologically compatible" plant community on well site disturbances. However, many important species of Fescue Grasslands were not available to include in this study. Limited availability and range of native species poses a continuing problem for native prairie revegetation.

Benefits

1) For continued access to endangered native prairie ecosystems, the petroleum industry must be able to demonstrate low operational impact on native prairie to other stakeholders (land owners, conservationists, government bodies, etc.).
2) More effective revegetation leading to native prairie conservation.
3) Lower reclamation costs (potential).
4) Revegetation guidelines directly applicable to native prairie.
5) Forum for discussion and education among all stakeholders.

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At last a special thank you to our colleagues Byron James and Denise Pewarchuk.

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Table 1. Description of treatments, Fescue Grasslands project.

Treatment	Description
Reference (Control)	undisturbed prairie to which the treatments were compared
Reclamation	a simple, 2 species mix, - low diversity, competitive species
Diverse	a diverse seed mix including over 15 species of early and late successional stages
Simple	a simple native grass mix consisting of species dominant in the undisturbed community - low/moderate diversity
Natural Recovery	no seeding - natural secondary succession

Figure 1. Map of Native Prairie Revegetation Research Project (Fescue Grassland sub-project) study area and example of study site layout.

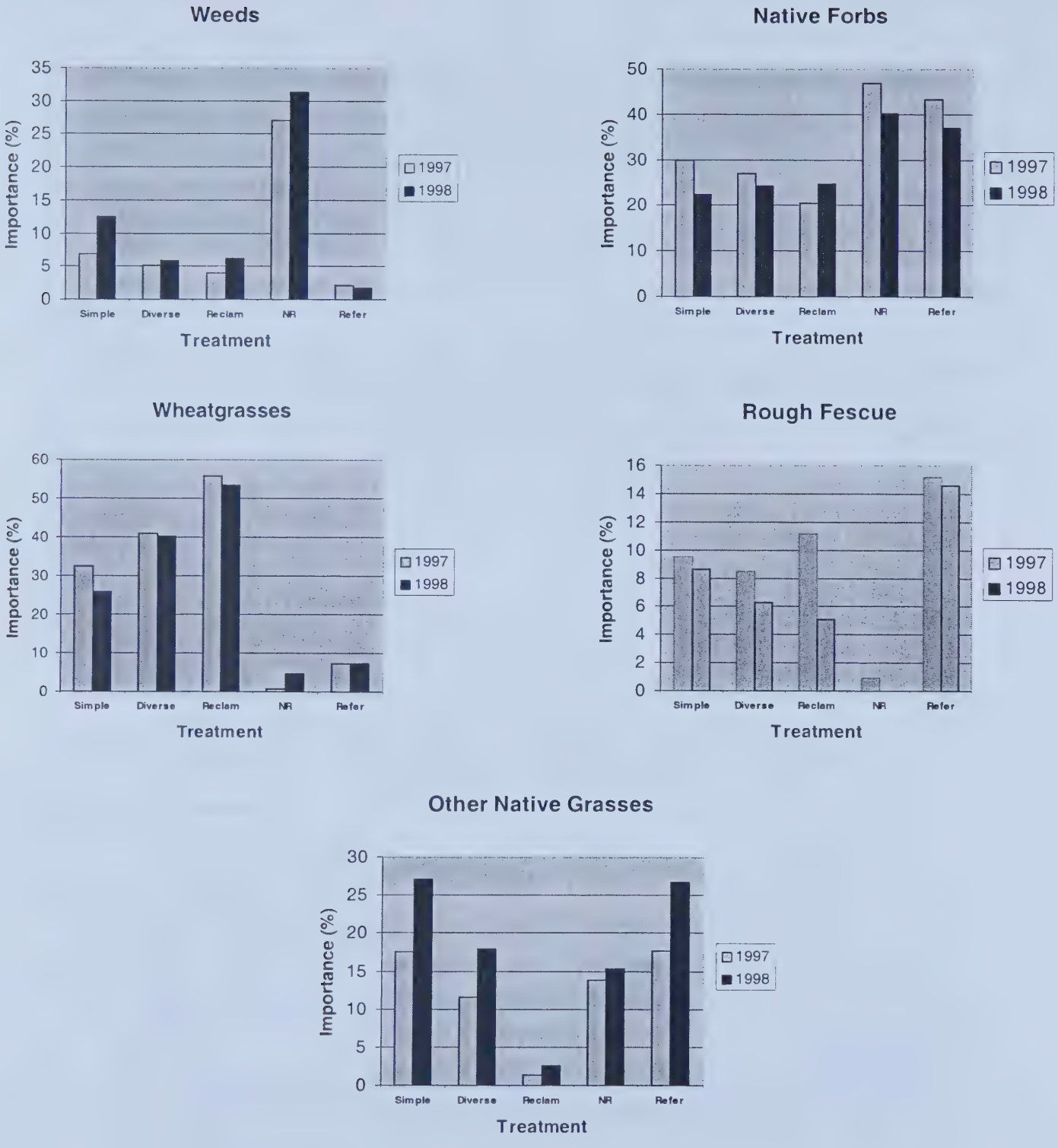

Figure 2. Importance value of selected plant groups on Mesic Chernozemic sites, Fescue Grassland Prairie sub-project (a. weeds, b. native forbs, c. wheatgrasses, d. rough fescue, and e. other native grasses).

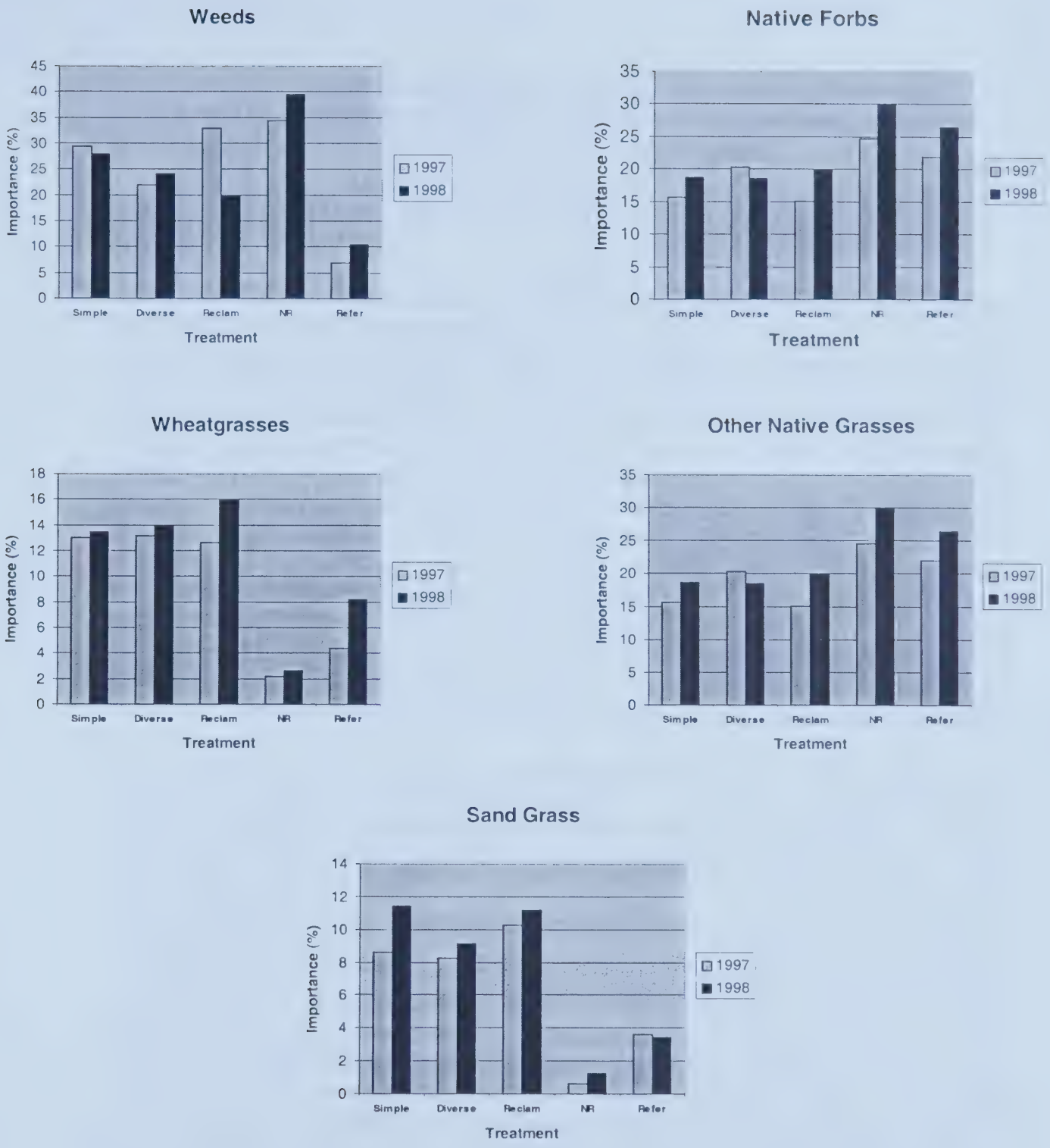

Figure 3. Importance value of selected plant groups on Sandy Sites, Fescue Grassland Prairie sub-project (a. weeds, b. native forbs, c. wheatgrasses, d. sand reed grass, and e. other native grasses).

Relative performance of native prairie grasses and forbs for revegetation of a pipeline disturbance on native prairie.*

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Abstract

The primary objectives of reclamation after pipeline construction on native prairie are to preserve the industrial resource (pipe stability) and the natural resources (edaphic and biotic) and to restore the land capability to at least the pre-existing level. Vegetation plays a pivotal role in meeting these objectives through erosion control, soil reconstruction and the initial vegetative cover that is the basis for the re-establishment of a desirable plant community. The choice of species for the initial cover of vegetation is therefore important. Funded by Express Pipeline Ltd. of Calgary, revegetation trials were begun in 1997 to evaluate the suitability of 59 species of native grasses and forbs for pipeline reclamation. Identical plot layouts were established at three locations in the mixed-grass prairie region in southeastern Alberta. The three locations, all within a 50 km area, have three soil types: clay loam, sandy loam, and loam. Grasses in the trial consisted of 23 species of with 2-4 sources of 7 species including cultivars from U.S. and Canadian sources in the Northern Great Plains. Forbs in the trials consisted of 19 species that originated from seed harvested from wild stands in Alberta and Saskatchewan. The plants displayed a wide range of responses to environmental and cultural conditions.

Plant response varied widely with respect to transplant survival, seedling emergence, first season seedling survival, seed production, spread by rhizome, biomass productivity, cover (live and litter), vigour, and apparent competitive ability. In general, cultivars of native species were more successful and more uniform in performance. Cultivars with above average performance included three cultivars of slender wheatgrass, Highlander, Revenue, and Hillcrest. Also excellent were Walsh western wheatgrass, Elbee northern wheatgrass and Lodorm green needlegrass. Trial species that were above average and originating from wild-harvested collections included blue grama harvested by R. and R. Wolfater of Eastend, SK and needle and thread grass harvested by R. McDougald of Maple Creek, SK. One source of junegrass that is widely used for revegetation in Alberta and Saskatchewan was not at all winter hardy– no transplants or seedlings survived the first winter at any of the three locations. Wild-harvested collections of wild licorice, dotted blazing star and purple prairie clover failed to establish by transplant or by seeding. Many other native forb lines performed poorly and are not likely to survive more than a few years. At this early stage of the study, it can be concluded that performance testing of native species seed sources is necessary in order to obtain predictable results. This means either cultivar development or a seed source identification system that provides a reasonable expectation of plant performance.

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Planning and Development Authority For Saskatchewan Rural Municipalities and Planning Districts*

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INTRODUCTION

In Saskatchewan, the primary responsibility for managing community planning, land use and development rests with the local municipality. The Planning and Development Act, 1983, c. P-13.1 (the Act) provides municipalities with the legal framework necessary to carry out community planning, establish zoning bylaws, require development permits, and manage land use on all lands within their jurisdiction. The Act enables municipal councils to develop
flexible planning bylaws to meet the needs and expectations of each municipality.

The purpose of this paper is to:
- highlight the planning and development responsibilities available to municipalities as prescribed by The Act;
- describe municipal bylaws available for use by municipalities to manage land use, development and reclamation;
- identify that municipal development processes complements provincial objectives and is not necessarily duplication; and
- confirm the importance of municipal consultation as an effective public relations initiative.

This paper is prepared based on personal working experiences of the author. The opinions and comments expressed are those of the author and should not be interpreted as the official views of Saskatchewan Municipal Affairs, Culture and Housing.

I. Planning and Development Authority in Saskatchewan

The Planning and Development Act, 1983, establishes the planning and land use authority in Saskatchewan for:
- the Minister of Saskatchewan Municipal Affairs, Culture and Housing;
- the Councils for both Urban and Rural Municipalities; and
- Planning Districts Commissions.

A. Ministerial Authority

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The Act provides powers to the Minister of Saskatchewan Municipal Affairs, Culture and Housing to co-ordinate the multitude of land use planning issues within the province. Generally, this includes the authority to:
- establish provincial land use policies;
- establish municipal planning commissions;
- authorize the adoption of municipal Basic Planning Statements, Development Plans, Zoning Bylaws; and
- undertake any study pertaining to land use.

B. Municipal Authority

The Act enables municipalities throughout Saskatchewan to administer local land use and development issues including oil and gas development and land reclamation through the adoption of land use policies such as basic planning statements, development plans and zoning bylaws.

The legislation anticipates that municipalities with the assistance of these bylaws will in effect:
- set out the desired framework for future development of their communities through defining goals, objectives and policies;
- clarify the municipal role and development expectations of land use and resource development;
- guide council in their decisions;
- reduce land use conflicts;
- empower council to enforce decisions, their bylaws and development permit conditions;
- provide opportunities for input by all affected interests in the community;
- inform the members of the community on how Council intends to direct and manage the community's needs and expectations; and
- establish a development framework for all parties to follow thereby creating certainty and consistency for the developer.

C. Planning District Commissions

There are currently 17 planning district commissions in Saskatchewan. Where commissions are established, it is advisable to check with the municipality regarding the necessity to consult the commission during the project planning stage of any development.

In general, the establishment of a planning district commission is to provide assistance to the affiliated municipalities respecting community planning and development issues. The commission provides a formal process for inter-municipal discussions of mutual interest and creates opportunity for consistent land use policies and zoning between the affiliated municipalities.

The duties of the planning district commission are reflected in Section 18 of The Act and may include:

- holding public meetings and publishing information on matters affecting land use and development affecting the district;
- assisting the Council of any affiliated municipality in the preparation of policy and zoning standards;
- reviewing and providing recommendations on existing bylaws, development permits and public works for adoption by the affiliated municipalities;
- studying developments within and adjacent to the district and recommend appropriate action to the affiliated municipalities; and
- identifying social, environmental and economic implications of commission recommendations to the municipalities.

A few Municipalities as in the case of the Great Sand Hills Planning District have established policies to consult the Commission on all development projects within a specific area of the Great Sand Hills. This Commission was established to ensure consistent bylaw administration by the four rural municipalities and to provide a forum to discuss development issues of mutual interest with stakeholders in the area. The significant increase in oil and gas activity, concern for appropriate reclamation practices and need for a trail network and management plan has consumed many hours of discussion for the Great Sand Hills Planning District Commission. The initiatives of the Commission have been noticed by industry. Whether this recognition is positive or negative, the concern of the Commission is to ensure the industry stakeholders implement the appropriate field practices which minimize impacts to the sensitive environment and save the company expensive reclamation costs. It is note worthy to identify that the standard operating procedures of the many companies is very similar to the objectives of the Great Sand Hill Planning District bylaws. This being said, one would expect in the extremely sensitive areas of the Great Sand Hills that development would naturally be restricted or discouraged in order to be consistent with the standard operating procedures. As such, there is a balance between the interests of the Commission and most company's standard operating procedures. It is evident for those working in the area that it is the field implementation techniques, which require fine-tuning in order to address the sensitive areas of the Great Sand Hills.

Looking at the rest of Saskatchewan, the majority of the other municipalities and commissions have not been so active in managing reclamation issues involving oil and gas development. This is likely due to the environmental and ecological differences between the Sand Hills and other areas of the province. The Great Sand Hills Planing District should be considered an exception to what how Commissions and other municipalities mange industry impacts.

II. Municipal Bylaws

The Act provides municipalities with significant authority to adopt specific policies and zoning regulations and to establish a development permit process to implement the bylaws. While these bylaws generally address local interests regarding land use,

development and municipal servicing, they can also establish specific development standards and practices for environmental reclamation of property.

A. Basic Planning Statement

A basic planning statement contains short declarations of a council's objectives for development in the municipality. It is usually suitable for urban and rural municipalities that are not experiencing large scale or numerous development proposals. A basic planning statement must: - contain a statement of the objectives for the future development of the municipality;

- contain a statement of objectives to be accomplished by a zoning bylaw;
- incorporate, insofar as is practical, any applicable provincial land use policies;
- be based on any studies and surveys that the minister may require or that may otherwise be appropriate; and
- address any other matter that council considers advisable.

B. Development Plans

A development plan may be more complex and broader in scope than a basic planning statement. It is suitable for urban and rural municipalities examining numerous development proposals or complex development issues needing special zoning regulations. The purposes of a development plan are:

- to serve as a framework whereby the municipality may be guided in making development decisions;
- to identify the critical problems, opportunities and community needs concerning the development of land;
- to set out the desired timing, patterns and characteristics of the future physical, social and economic development of the municipality;
- to establish and specify the programs and actions, and a capital works program necessary for the implementation of the development plan; and
- to outline the methods whereby the best use and development of land and other resources in adjacent municipalities, or affected areas immediately abutting the municipality, may be coordinated.

C. Zoning Bylaws

The primary legal and administrative means of implementing a policy plan is the zoning bylaw. It divides a municipality into zoning districts and regulates the development and use of land in those districts. A zoning bylaw permits a council to set local standards for the subdivision and use of land, and helps manage the delivery of municipal services and resources to new development.

Each zoning district may have regulations specifying:

- the area and dimensions of new lots or parcels of land;
- the size, location, dimensions, and types of buildings;
- the provision of parking spaces or payments in lieu;
- outdoor storage and landscaping;
- the size and location of signs and lighting;

- the removal of soil or vegetation; or
- sound or noxious emissions.

Most importantly, the zoning bylaw
- establishes development permit procedures;
- establishes zoning district development regulations and development standards to manage land use issues pertinent to the zone;
- establishes a Development Appeals Board and appeal mechanisms; and
- establishes the specific land use zones in the municipality.

III. Provincial and Municipal Interests

The legislative authority established under The Act for municipal management of local land use and development interest clearly emphasizes the importance for local decision making regarding municipal and community interests. It should be noted that the Crown under Section 213 of The Act is also bound by the municipal bylaws.

Saskatchewan Municipal Affairs, Culture and Housing, provides a coordination role between municipal interests and provincial interests to ensure:
- provincial interests are incorporated within the local zoning bylaws;
- bylaws do not conflict with provincial interests; and
- municipal interests are considered or incorporated within provincial initiatives.

The provincial legislation and processes which address environmental impact assessments, development on crown lands, critical wildlife, water quality and so forth do not necessarily address local development impacts and municipal servicing interests. The authority to manage these issues including location of development, minimizing land use conflict, ensuring adequate municipal servicing such as road construction and maintenance, fire protection and other local issues rests with the individual municipality.

The various approval processes under Saskatchewan Environment and Resource Management, Saskatchewan Agricultural and Food, Saskatchewan Energy and Mines, municipalities and other provincial agencies are separate regulatory processes which complement each other. These complementary functions ensure the environmental, agricultural, resource and municipal interests are addressed at the project planning stage. It is important to note that these processes can be undertaken concurrently and that a development may require approval from each respective authority before it can commence.

IV. Consultation and Resolving Issues

A. Municipal Consultation

Rural municipal councils have significant pressures to reduce taxes, improve road conditions, and provide additional community and municipal services. With one meeting a month and limited staff resources, they are expected to respond to immediate requests

for development permits, negotiate servicing agreements, and resolve local conflicts between neighbors and developers. With the additional pressures on municipalities by increased oil and gas development, reassessment/tax changes and road rationalization occurring throughout the transportation system, it has become evident that municipalities are very sensitive to and concerned with developments which impact life expectancy of roads.

Through effective municipal consultation and public relations, companies will find very cooperative councilors and administrators willing to assist, provide information and problem solve issues. However, this may not be the case where the council or administrator has experienced:
- little or no consultation from a company;
- negative situations such as road damage by rig moves with limited resolution:
- insensitive field crew practices of demanding immediate permits as the rig sits outside the municipal office; and
- suggestions of potential legal action against a municipality. These and other examples experienced may suggest that previous conflict and frustration between municipalities and oil and gas companies is a result of:
- a limited understanding and compliance with municipal processes by companies and/or the contractors in the field; and
- a limited understanding of the oil and gas industry, its operations and time frames by municipalities.

To save both time and money, the company should ensure its contractors are informed of the municipal development procedures. Undertaking effective public relations with a municipality to clarify your company project will expedite operations. Municipal consultation and development permit processes should be incorporated within the standard operating practices. Consultation should include:
- clarifying terms used with clear language;
- meeting with the council to discuss standard operating procedure similarities to municipal expectations and bylaw requirements; and
- completing a development permit application where applicable.

It is apparent that many industry standard operating practices are similar to municipal expectations and bylaw requirements. In the majority of cases, delays with the development permit process could have been avoided through improved consultation practices in the early planning stages of the project.

It is worthy to note that municipalities have a responsibility to work cooperatively with the industry to ensure a balance between the municipal servicing interests and industry's operational needs are achieved. This
requires effort by municipal councils to become informed of industry operations and terminology. As projects develop, municipal awareness of the industry 's activities and impacts to municipal services becomes evident.

Recent efforts over the last few years on part of both municipalities and industry to understand each others interests has been very positive. Improved communications between the project team and the municipal council is key to expediting any project. Experience has proven that those companies that undertake public relations with municipalities explaining the project and listening to the municipal perspective, establish an invaluable working relationships which may lead to cost saving approaches and expedited municipal decisions. Those that don't establish a good working relationship may feel they become bogged down in municipal processes and undue delays. How your company relates to the municipal sector in Saskatchewan is yours to chose. With effective consultation, you will find positive opportunities that can provide your company both short and long-term cost savings.

B. RESOLVING ISSUES

Local municipal issues with the oil and gas industry range from:

- the need for development permits,
- misapplication of zoning authority by municipalities,
- development standards,
- reclamation practices,
- depth of flowlines under roads,
- location of seismic testing on public road right of ways vs. private land, and of course
- road impacts caused by battery sites, heavy hauls or possibly rig moves in the middle of a rainstorm.

It should be noted that these are certainly local issues requiring local resolution not provincial intervention.

The majority of these and other local issues are resolvable at the project planning stage. The company is responsible for obtaining all necessary permits prior to development. Therefore, it is the company -s responsibility to consult the municipality well in advance of the project to ensure it has met any municipal development requirements.

Your consultations and discussions with a rural municipality should include:

- zoning requirements for the project;
- need for and if necessary submission of a development permit;
- the municipality's past and current experiences with the industry and/or with your company including road issues;
- local environmental considerations
- road impacts and methods for resolution;
- any unresolved issues pending from past projects; and
- collaborative approaches with council when resolving issues rather than confrontational approaches.

By allowing sufficient time for municipal consultation, and taking the initiative to become familiar with the municipal processes, your company and industry can earn the municipality's trust. Earning a municipality -s trust will certainly expedite future projects.

Follow up consultation is also a very important public relations tool to ensure your company, crew, or contractor complied with the municipality -s requirements. You may find the results surprising and answer some of the questions and concerns you may currently have regarding your past municipal experiences. Follow up with the municipal council to ensure the finished job met with their acceptance. It may be as simple as a phone call to the administrator or a quick visit to a council meeting.

Where your projects involve more than one municipality, you may wish to consider a meeting between all affected municipalities to discuss your project activities and identify any issues and options which could improve working relationships and expedite approvals.

V. Conclusion

Municipalities in Saskatchewan look very favorably upon the oil and gas industry and have done extremely well in accommodating industry -s interests given the increasing activity which has occurred. Today, we hear of a few municipalities exercising their authority to address specific issues affecting the municipality -s ability to manage their interests. This should not be perceived as all municipalities. Road maintenance agreements or development permits are a municipal response towards incorporating local servicing and development issues into the project planning stages and consultation processes of a company.

With increasing oil and gas development and reclamation issues, municipalities have options to pursue their legal authorities to manage development issues. However, it must be recognized that most municipalities prefer to cooperate and mutually resolve any development issues first and view the use of municipal bylaws as a last resort. Therefore the most effective opportunity for industry to address these local interests is through open two way communication directly with the municipality well in advance of the project. To achieve this, including municipal consultation within your company's standard operating procedures will be most effective. Early collaboration with municipalities should result in effective methods and greater opportunity to address local development issues, save time and most importantly costs.

Use of Ecological Management Planning In Western Saskatchewan*

Wayne Pepper and James Ireland, Erin Consulting

Introduction:
The need for ecological restoration and rehabilitation can often be prevented or much reduced through a planned approach to management. If this pro-active slant to management is linked to an understanding of what important ecological processes and functions are jeopardized by development, the effectiveness of the planning should be enhanced. ERIN Consulting Ltd. is testing this concept of "ecological management planning" in the Hatton gas field of southwestern Saskatchewan.

Currently, companies seek approval for gas well developments from regulators through a process called Environmental Protection Plans (EPPs). EPPs address environmental concerns on a site by site basis largely to alleviate problems with the development stages of oil and gas production. A new EPP is prepared each time a company seeks approval for development of new or modified wells, flow lines, roads or compressor stations. The EPPs are repetitive for each set of development plans and never address the sum total of impacts on the environment. Accumulative effects of these developments are resulting in serious fragmentation of native habitat and redundancy of gas facilities and infrastructures. Little attention is paid to longer term operating impacts or eventual decommissioning. A method of combining available information into a pro-active plan designed to reduce accumulative impacts and cut overall costs to the gas company is needed.

ERIN Consulting, an environmental consulting company based in Regina, is using an interactive ecological approach to planning, using a combination of digital geographically referenced data bases and other locally collected information. Geographic Information Systems, (GIS), technology is used for analysis and public consultation and ground based data are coupled with a basic understanding of the ecological functions and processes of the local ecosystems to refine the information into an integrated plan which attempts to address all stake holders concerns.

Methods:
Digital Saskatchewan Soil Survey data from the Institute of Pedology , U. of S., the Thematic Mapper, TM, satellite image for the area in digital form obtained from Radar Sat in Edmonton, and a digital map of the existing gas field developments supplied by the company, are critical components of the initial planning exercise. Information from previous ecological field investigations are used to add to the overall understanding of the area.
The powerful GIS software facilitates integration of the various data bases such that a series of electronic map overlays are produced. These maps reveal broad vegetation

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communities and habitat types, farmsteads, roads, trails, gas well sites, water bodies of various types and significant geological features such as steep slopes, sand dunes, saline areas and agriculturally altered lands. The resulting rough maps provide some indication of the best places to locate future gas developments, accounting for environmental sensitivities and economic savings to the company. We stress that overall costs to the gas company can be reduced if their activities are planned to integrate smoothly with the wildlife habitat and traditional land issues of the area.

Local landowners are encouraged to contribute to the plan. A primary concern of both landowners and wildlife managers is the need to control proliferation of roads and trails, which fragment the landscape and increase vehicular traffic. The plan has to address these concerns as well as timing of gas production activities to eliminate or reduce disturbance to humans and wild life during sensitive time periods. Specialized forms of transportation may be advisable for certain areas or access to these areas may be curtailed entirely. On the other hand, opportunities to reduce costs to the company are identified at every opportunity.

Once the inputs from all the stakeholders are incorporated into the plan, it is finalized and submitted for approval to various regulators such as Saskatchewan Environment and Resource Management, PFRA, Saskatchewan Agriculture and Food, Saskatchewan Energy and Mines and the Great Sandhills Planning Commission. Once approved, it will act as a guide and basis for developing operating plans of the company and Local Operating Agreements, (LOAs).

The EMP is intended to be a dynamic plan from the standpoint that it encourages continuous improvements in protecting ecological integrity and cost cutting while following the principles and objectives laid out in the plan. The need to recognize and protect sensitive soils, vegetation and wild animals will not change nor will the need to maintain a healthy profit margin for the gas company. The ways of accomplishing these goals may change as time passes throughout the life of the gas production.

Conclusion:
The Ecological planning approach combines the best scientific and anecdotal ecological, economic and cultural characteristics of the area, the concerns of stake-holders, the logistical operational issues and the long term considerations into the equivalent of a regional land use plan. The program has been accepted by individual gas companies but ERIN Consulting has identified that there are opportunities to make this approach even more effective through combining the ecological management planning for all gas operators in a particular area. This would indeed be a truly integrated approach.

Physical Restoration of the Kingsmere River in Prince Albert National Park*

Michael Fitzsimmons (Parks Canada) and Guy Melville (Saskatchewan Research Council)

1. Abstract

The Kingsmere River (54.03°N, 106.42°W), located within Prince Albert National Park, flows approximately 3 km from Kingsmere Lake to Waskesiu Lake. It is a river in name only, and would be better characterized as a cold, clear-water boreal stream. The Kingsmere River was modified by the construction of a breakwater, a diversion canal and several dams in order to improve accessibility by motor boats. Over a period of decades, much of the Kingsmere River was gradually transformed from a wild river into a regulated boat canal. Prince Albert National Park was established to keep lands and waters unimpaired for future generations, but aquatic systems (lakes, rivers and fish) were manipulated and exploited during the same time period that terrestrial ecosystems (forests, mammals and birds) were largely preserved and protected.

Studies carried out by the Saskatchewan Research Council and Prince Albert National Park between 1993 and 1996 revealed substantial ecological differences between the Kingsmere River and a reference stream that lacked similar human modifications, the MacLennan River. Sites along the Kingsmere River had lower variability in water depths, water velocities and substrate particle sizes. This lack of habitat diversity was associated with reduced species richness for fish and stream-edge plants. Fish and invertebrate fauna adapted to flowing-water habitats were neither abundant nor widely distributed in the Kingsmere River relative to the MacLennan River. Fallen trees and beaver dams played an important role in directing current flow and changing channel morphology, adding temporal dynamics to the MacLennan River system. The removal of large woody debris and beaver structures from the Kingsmere River resulted in a static channel and less turbulent flow. The picture which emerged was that the spatial and temporal heterogeneity of both habitats and biota were much less along the Kingsmere River than would be expected under natural conditions. The ecological changes caused by the alterations of the Kingsmere River were determined to be largely reversible, primarily because of the remnant physical and biological diversity maintained in a 400 m section of rapids which boaters have portaged around since the 1940s.

Upon completion of these studies, Parks Canada began to restore the original natural characteristics of the Kingsmere River in accordance with the park's management plan. The objectives of restoration actions included (i) increasing water velocities and dynamic channel movement; (ii) increasing the abundance and extending the distribution of organisms adapted to flowing-water conditions; (iii) removing artificial obstacles to the

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movement of fish between Waskesiu Lake and Kingsmere Lake; and (iv) reintroducing important biotic elements such as large woody debris and beaver works.

Restoration was initiated in 1996 when the park's lake crew removed a submerged dam on the outflow of the original river channel, adjacent to Waskesiu Lake. In 1997 the rock and timber breakwater at the river inflow was dismantled by the Kingsmere District Warden, the park fire crew, and Young Canada Works students. Later the same year, park staff opened the original river channel using explosives and fire crews blocked the diversion canal with sandbags. Work scheduled for 1998 was cancelled due to mild weather that allowed open water to persist on the river throughout the winter. During the colder winter of 1999 contractors trucked sand down the frozen river to re-establish a beach ridge across the former diversion canal. In the fall of 1999, the remaining dam on the river is scheduled for removal. It is anticipated that this will be a public event involving both citizen volunteers and park staff. Several other physical restoration works remain to be scheduled pending the availability of funds, including the elimination of erosion problems at the public access point used by boaters.

Physical restoration of the Kingsmere River has been been a labourious and unglamorous effort to move tons of rock, sand and timber by many individuals and organizations. The work has been protracted due to lengthy public consultations, intra- and inter-agency tensions pursuant to environmental assessments and other decision-making processes, and limitions in financial and labour resources.

Although major components of the physical channel rehabilitation have been completed, biological restoration will take many more years. A long-term monitoring program carried out by the Saskatchewan Research Council and Parks Canada will evaluate the success of restoration efforts. It is hoped that future visitors to the Kingsmere River, one of the most popular aquatic ecosystems in Prince Albert National Park, will witness the revitalization of the river's physical dynamics and biological diversity. Unfortunately, the Kingsmere River is one of the only streams in the region where restoration works have been initiated to reverse the ecological degradation caused by impoundments and other human modifications.

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Fire Management For Prince Albert National Park - Planned and Random Ignition Prescribed Burns*

Jeff Weir - Vegetation Specialist - Prince Albert National Park

A modified fire management strategy has been developed for Prince Albert National Park as the historic full suppression strategy is no longer consistent with the Park's mandate to protect for all time the ecological integrity of an area representative of the Southern Boreal Plains and Plateaux natural region. In order to maintain the ecological integrity of this region, ecological processes such as wildfire must be managed with minimal interference. The intent of the full suppression strategy was to minimize the area burned and consequently to exclude this process from the region. A recent study of the Park's fire frequency has documented a significant change to less frequent fire disturbance since 1945 which has been attributed, in part, to fire suppression actions. Consequently, a modified fire management strategy has been developed that is intended to restore the ecological role of fire in Prince Albert National Park.

Within the logistical limitations of the Park, random ignition wildfires will be allowed to burn in the containment fire management unit , figure1, provided they meet previously approved conditions described in random ignition prescribed burn plans. A continuous fuel break will be created around the perimeter of the containment unit by implementing planned ignition prescribed burns. The fuel break will consist of a wide strip of land on which the vegetation is naturally or otherwise less flammable than that surrounding it so that fires burning onto these lands can be more readily controlled. If a fire threatens to escape the unit, it will be suppressed directly or indirectly along the fuel break. The fuel break will be established incrementally and where possible will utilize existing landscape feature that facilitate the control of wildfires. The containment fire management strategy will be progressively implemented as containment opportunities for localized areas in the unit are created.

A full suppression unit will surround the containment unit, figure 1. In this unit wildfires will be suppressed in a manner that is designed to extinguish the fire as quickly as possible. The fire management strategy of this unit is consistent with that of adjacent Provincial lands. Consequently, this unit serves to buffer the difference between the Provincial full suppression and Park containment fire management strategy..

The Canadian Fire Behaviour Prediction (FBP) Model, and historic weather data bases will be used to develop prescribed burn plans. Prior to their approval these plans will be reviewed nationally by Parks Canada fire behaviour experts. They will also be reviewed by Saskatchewan Environment and Resource Management (Forest Protection and Fire Management Branch) and Weyerhaeuser Canada Ltd. (Saskatchewan Timberlands) personnel. These prescribed burn plans will be revised to minimize area of concern before they are submitted for approval to the Park Superintendent.

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The risk of wildfires burning valued Park and Provincial resources will be minimized by ensuring that associated hazard reduction strategies are developed and implemented. Throughout the implementation of this strategy, the Park recognizes the partnership role of Saskatchewan Environment and Resource Management (Forest Protection and Fire Management, and Ecosystem
Management Branches) and Weyerhaeuser Canada Ltd. (Saskatchewan Timberlands). The Park is committed to communicating and working closely with these partners. It will also communicate with municipal and First Nation governments, adjacent landowners, park and provincial stakeholder groups, and the general public. Feedback from these groups is encouraged and will be reviewed annually by Park managers. Where the Parks mandate will allow, the Parks fire management plan will be revised in order to minimize areas of concern.

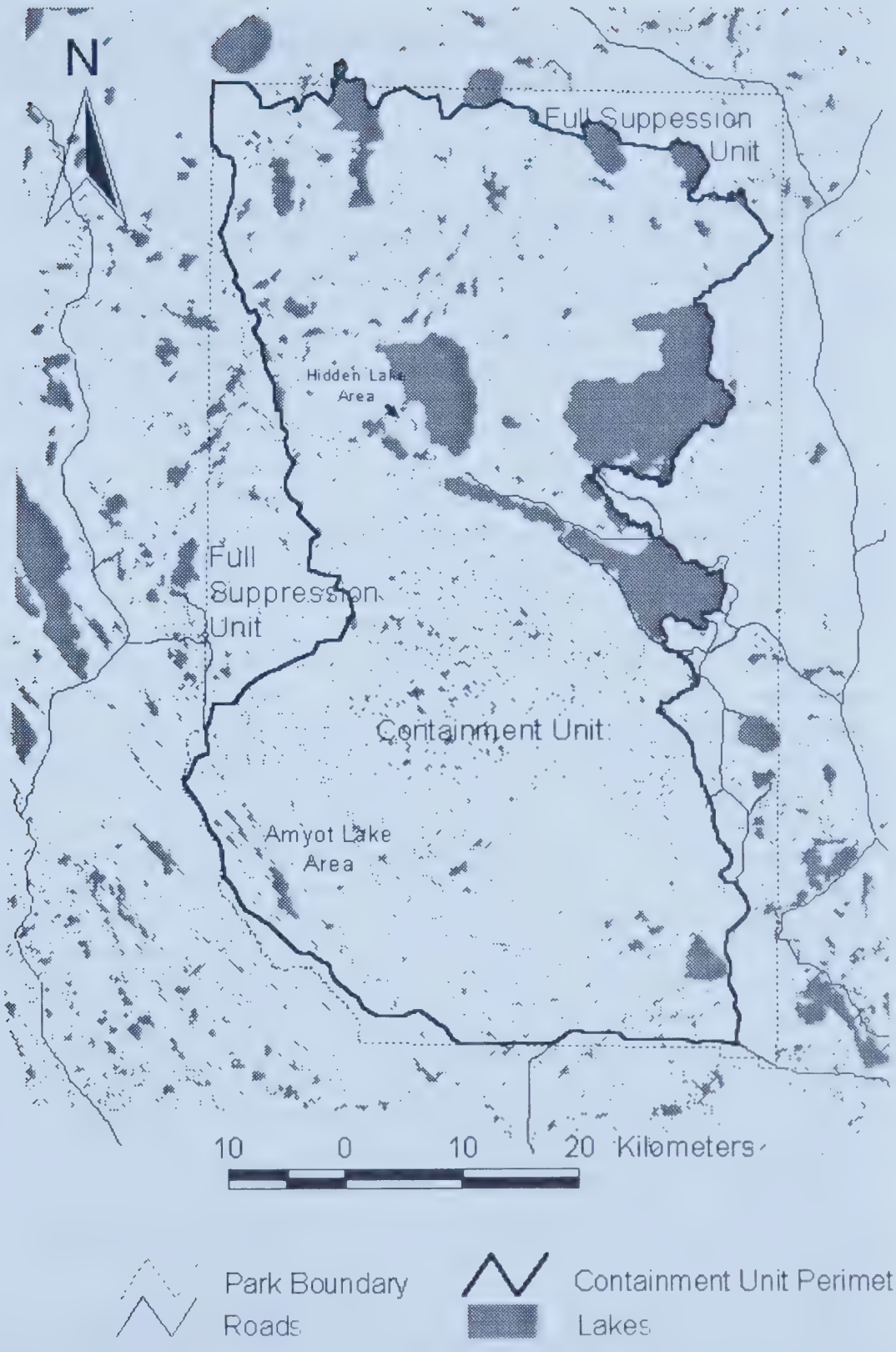

Figure 1: Map of Prince Albert National Park showing the location of Suppression and Containment Fire Management Units.

Ecosystem Management Applied to Riparian and Aquatic Habitat Restoration*

Karl Lauten, Saskatchewan Environment & Resource Management, Regina

Abstract:

Ecosystem-based management is not a new concept but its widespread acceptance and implementation by resource managers in Saskatchewan has just begun. It involves both conservation of resources to sustain the provision of products from the ecosystem to society, as well as the management and adaptation of human and natural events to protect or conserve the structures and functions of an ecosystem which conveys upon itself resilience and the capacity for renewal. The ecosystem management approach presents itself as a new paradigm that challenges the environmental, social and economic values of many of our past and present land, flora and fauna, and water use practices. Among the important ecosystem components which have been substantially altered by past practices are riparian habitats. This presentation attempts to identify the importance of riparian areas and their associated aquatic habitats, to identify the major causes of riparian habitat loss, and to provide some suggestions for maintaining and restoring riparian area structure and function in all watersheds of Saskatchewan.

Riparian habitats are areas adjacent to aquatic systems (streams, rivers, wetlands, bogs, lakes) that contain physical, chemical and biological features of both aquatic and terrestrial ecosystems which interact with each other. Though comprising only a few percent of the total landscape riparian areas are being recognized as one of the most important components of the ecosystem and that they are essential to the ecological health of watersheds. Some of the significant ecological and social values associated with riparian areas include: provision of critical wildlife habitat and travel corridors, direct contributions to aquatic and terrestrial habitat diversity and food resources for aquatic biota, trapping of pollutants, water purification, reducing intermittency of flow, slowing of the rate of movement of energy, materials, and nutrients in watersheds, erosion and flood control, recreation and aesthetics. In virtually every province, past land and water use practices have resulted in various levels of alteration and damage to much of the riparian habitats and associated aquatic habitats in all but the most remote of watersheds. Wetland drainage, reservoir construction, channelization, and shoreline development have altered hydrological regimes or directly involved removal of riparian vegetation and resulted in the most severe damage to riparian habitats. Agricultural practices, forest harvesting and road construction either because of the extent of activity on the landscape or their occurrence too close to the shorelines of waterbodies have also contributed to the destruction of riparian habitat and to the loss of riparian ecosystem function.

Although the main causes of riparian habitat loss or damage are known, prevention of further losses and restoration of impacted areas is currently hampered by a lack of information about riparian habitat (ie. inventories), a lack of riparian ecosystem

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management guidelines, a lack of an ecologically-based riparian and aquatic habitat classification system, as well as by conflicting mandates amongst government agencies responsible for resource management. It is proposed that application of ecosystem-based management principles in all aspects of land and water use management practices can provide the framework to overcome the barriers to riparian habitat management and restoration. The ecosystem-based management approach emphasizes partnerships between stakeholders, multidisciplinary planning between agencies, and a common commitment to protection of ecosystem health and integrity as a means to overcome the historical sectoral or narrow view approach to resource management. Application of ecosystem-based management to riparian and aquatic habitat management and restoration could also provide the means for resolving many ecological and environmental issues beyond those related to water resources. Positive steps to apply ecosystem-based management have been initiated in Saskatchewan.

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Restoration based on ecological function: grazing management in an endangered Australian ecosystem*

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1. Abstract

One of the primary conservation concerns worldwide is the loss of natural habitat and associated ecological processes. Indeed, many ecosystems have been so greatly modified that establishment of reserves is no longer an option (Sinclair et al. 1995). In such cases restoration is essential, and understanding the processes regulating a system can greatly facilitate restoration efforts. White box (Eucalyptus albens) woodlands are among Australia's most endangered ecosystems. They have been extensively cleared, and remnants are threatened by weed invasion, cessation of fire, and grazing. Our study investigates grazing in white box woodland at Burrendong Dam in the Central West region of New South Wales, Australia. At Burrendong, grazing (by domestic sheep and cattle, feral rabbits, and high numbers of kangaroos) has replaced fire as a major regulatory process. Four grazing treatments were established on the foreshores of Burrendong Dam in February 1997: exclusion of all major vertebrate herbivores; exclusion of kangaroos, cattle and sheep; exclusion of cattle and sheep; and unfenced control, in woodland (intact canopy) and grassland (cleared woodland). We monitored understorey composition, woody regeneration, and the soil seed bank over a two-year period. Using the results from this study and additional information from the literature, we developed a state and transition model of change in white box woodland. This type of modelling is a useful tool when considering restoration potential of white box woodlands, and may be applicable to other communities.

2. Introduction

Australian ecosystems provide a unique restoration challenge. The climate is often unpredictable, with droughts followed by heavy rain and flooding. Catastrophic fires are associated with this weather pattern, and the soils are ancient and nutrient poor. Most plants are drought adapted, recruit under specific conditions and flourish on low nutrient soils. As a consequence of low nutrition and variable environmental conditions, composition of many communities is essentially event-driven. Management over the past 200 years has altered the natural regime by removing fire, introducing sustained grazing, and increasing nutrients (Benson, 1991). This has favoured introduced weeds over native

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species. For restoration to proceed, we need to understand how these changes have altered the processes underlying community composition.

Box woodlands in eastern Australia, particularly White Box (Eucalyptus albens) woodlands, have been severely degraded since European settlement in the early 19th century. As much as 90% of the original box woodlands have been cleared (Benson, 1991), and less than 0.01% of White Box woodlands remain relatively unmodified (Prober & Theile 1993). Once a continuous belt of vegetation stretching the length of New South Wales, the woodlands now consist of small remnants in varying degrees of decline surrounded by grazing and cropping land. Programs to encourage conservation and restoration of remnant bushland include subsidies for stock fencing and tree planting, however, stock grazing is only one of several processes contributing to degradation of white box woodland.

Our study investigates the effect of excluding sheep, cattle, kangaroos, and rabbits on white box woodland understory. One objective is to determine whether fencing alone is a viable way to promote woodland recovery, and if so, which animals must be excluded and which patches are most likely to be saved. Using the information from our study and the research of others, we have created a state and transition model (sensu Westoby et al. 1989) to help determine which management actions would be most appropriate in particular situations and to highlight barriers to restoration. The state and transition model recognises that a community can exist in several stable states and combinations of 'events' or management actions can cause transitions between states. Each state and all transitional conditions are explicitly outlined. State and transition models have proven useful in other communities including arid Australian rangelands (Westoby et. al. 1989) and woodlands (Yates & Hobbs 1997) and the Serengeti (Dublin 1990).

3. Methods and Preliminary Results

3.1. Study Area-

The study area is part of a large catchment managed by the Department of Land and Water Conservation, NSW. It is located on the foreshores of Lake Burrendong (32o 40' S, 149o 6' E) on the western slopes of the Great Dividing Range in eastern Australia. The climate is temperate, with warm summers (mean max. 29-33□symbol 176 \f "Symbol" \s 12□°□ C), cool winters (mean min. 2-3□symbol 176 \f "Symbol" \s 12□°□C), and a median annual rainfall of 666 mm. The landscape is dissected by the Macquarie and Cudgegong Rivers, which were dammed in the 1960's to create Burrendong Lake. The box woodlands on the lower slopes were largely cleared of trees to promote pasture growth in the 1800's. There is currently no permanent habitation, but sheep and cattle are grazed under license. There are large numbers of eastern grey kangaroos and rabbits (Newsome & Hik, unpublished data).

When the land was reclaimed, it was in very poor condition, with large expanses of noxious weeds, little perennial cover, and widespread sheet erosion. The Soil

Conservation Service of New South Wales undertook major restoration efforts in the 1960's, including complete de-stocking, rabbit control, and seeding of clover (Colclough 1968). They successfully re-established substantial perennial cover, controlled weeds, and in some cases encouraged dense tree regeneration. However, the resulting system is far from pristine white box woodland.

In February 1997, we established fences to investigate overall grazing impact and test for differences between the effects of different herbivores. The experiment is replicated in four blocks. Within each block, there are eight 25m by 25m experimental plots, distributed in woodland (intact canopy) and grassland (canopy cleared). There are four treatments: control (no fence) stock fence, kangaroo fence (also excludes stock), and rabbit fence (also excludes stock and kangaroos), for a total of 32 plots (4 replicates of each habitat/fence combination).

3.2. Understory Composition

In ten permanently marked 1m2 quadrats in each experimental plot we estimated areal cover of all plant species and total plant cover in each quadrat in March 1997, March and October 1998, and March 1999. We also measured and identified all tree and shrub seedlings under 50cm tall in each quadrat. Every four months, we made a complete list of all plant species present in each 25m-by-25m experimental plot.

Species richness was higher in woodland plots (40-45 spp) than in grassland plots (32-40 spp), though the difference was not statistically significant. Woodlands were significantly less weedy than grasslands (Exotic/Native ratios 0.9 for woodland and 1.3 for grassland; $p<0.05$). Species richness generally increased with increasing exclosure, with the largest increases caused by kangaroo exclusion and rabbit exclusion, however this trend is not statistically significant.

Overall plant cover and cover of each species declined from 1997 to 1998, because of drought. In general, lower grazing pressure (more herbivores excluded) resulted in more rapid recovery from drought for native perennial grasses. Data from March 1999 indicate that exclusion of all herbivores was necessary for native perennial grasses to increase in grassland plots: percent cover (mean ± 1 SD) was 16±7% in complete exclosures and 6±5% in other plots. Exclusion of sheep and kangaroos was sufficient to allow some increase in woodlands but the increase was small: percent cover was 2±2% in unfenced plots and stocks fences compared to 5±3% in kangaroo fences and complete exclosures, are there was considerable variability between replicate sites.

Significantly, only 24 E. albens seedlings were recorded in quadrats in the course of the study. All seedlings were found in wooded plots and only in October 1998 and March 1999 (post-drought), predominantly on bare soil.

3.3. Germinable Soil Seed Bank

The germinable soil seed bank was sampled in October 1998 and March 1999. A total of 30 cores (5 cm diameter and 5 cm deep) were taken from each exclosure. Bulked samples were divided in half and spread into germination trays containing sterilised potting mix. Ten extra trays with only sterilised potting soil were prepared as controls. All trays were grown under standard glasshouse conditions (25°C average daily high and 10°C average daily low). Germinates were identified and removed as soon as possible after the first vegetative leaves were produced, and representative plants were grown to an identifiable age to confirm identifications.

The most notable difference was between habitat and season. Overall, woodlands had approximately 6.4 seeds/ cm2 compared to 8.9 seeds/cm2 in grasslands. The woodlands also had a higher number of forbs than graminoids. Overall, the spring samples had approximately 1.9 seeds/cm2 while the summer samples had approximately 8.9 seeds/cm2. The native:exotic species richness for the germinable soil seed bank was only 0.23. The most common germinates were Vulpia bromoides or Vulpia myuros, both problematic annual weeds. Only two overstory species were found in the seed bank, one E. albens and one Callitris glaucophylla.

3.4. Transplants

In April-May 1998, we planted 20 seedlings each of three native woodland species in each experimental plot. We chose Themeda australis (kangaroo grass), once the dominant grass, and now nearly extirpated by grazing; E. albens (white box), the dominant canopy tree; and Callitris glaucophylla (white cypress pine), another canopy or sub-canopy species. The purpose of this experiment was to determine the effect of clearing history and grazing by different herbivores on the growth and survival of important structural species. Transplants were monitored every four weeks (more frequently immediately after planting) for one year. We recorded height, survival, condition, signs of herbivory, and identity of browsing animal if it could be determined.

There were differences in both habitat and feeding preference between herbivores. Rabbits browsed Callitris most frequently, while sheep tended to browse E. albens. In control plots, rabbits and kangaroos caused more mortality in woodlands while sheep and cattle caused more mortality in grasslands. Themeda mortality was highest in grassland (81% versus 46% in woodland), and mortality in grassland was 80%-90% with herbivore access but 35% in complete exclosure. In woodlands, Themeda mortality was lowest in the absence of sheep and knagaroos (60-70% unfenced or stock fence, 25-35% in kangaroo fence or complete exclosure). For E. albens in both habitats mortality was 25% in control plots and 5-10% in all fence treatments. Mortality of Callitris in unfenced plots was 35%, in stock fences and kangaroo fences 15-20%, and in complete exclosures 0-10%. These differences were not significant in all cases.

4. 'State and Transition Model' and Conclusions

A state and transition model was constructed to illustrate the major processes operating in this ecosystem (Fig. 1). Vegetation states and transitions were identified from either historical description (SCS 1980, Colclough 1968) or from communities currently recognisable at Burrendong. The model is based on historical management, our current experiments and published results of others. Eight habitat states and 14 transitions were identified. We also identified two asymmetric boundaries to restoration, which indicate when a system will not return to a previous state by implementing the previous disturbance regime.

The original woodland community (S1) consisted of E. albens with an understory of perennial warm season grasses, such as T. australis, scattered native forbs and occasional shrubs. Patchy fire and light grazing by marsupials likely maintained this state. The introduction of stock in the early 1800's probably forced the original woodlands towards an understory dominated by cool season perennials such as Danthonia (S2). Clearing to improve pasture, and subsequent grazing (T2 and T3) changed much of the woodland to native grassland (S3) (Colclough, 1968, Adamson & Fox, 1982, Benson 1991).

S2 was probably maintained by light to moderate stocking, and could have reverted to S1 if stock were removed or grazing was of short duration; however, as grazing continued the reversion to S1 (T4) became less likely as palatable species disappeared. The progressive loss of propagules of native species creates a boundary (B1) preventing a return to S1 (Prober & Thiele 1993). S3 consisted primarily of cool season perennial grasses and native forbs, and could have been maintained by light grazing. S3 could switch to S2 if disturbance provided bare soil, E. albens seed reached the site, grazing pressure and seed predation was low, and weather was favorable (Clayton-Greene and Ashton 1990) (T5), probably a rare occurrence.

Increased grazing and nutrients in S3 could have promoted exotic weeds and encouraged less palatable native perennials such as Bothriochloa (T6). This state, Mixed Pasture (S5), was likely maintained under moderate grazing, with periodic heavy grazing in good seasons. Clearing, heavy grazing, and weeds (T7) may cause a similar shift from S2 to S5 (Adamson & Fox, 1982).

During the early 1900's, grazing pressure at Burrendong increased further, rabbits became abundant, the effects of drought became more pronounced, and S5 degraded to Ruderal Weeds (S6, T10) (Coulclough 1968). In S2 sites where clearing did not occur but grazing, stock camps, and rabbit activity increased (T8), a Weedy Woodland (S4) resulted. S4 is transitional since E. albens seedlings compete poorly with exotic weeds and increased nutrients appear to hinder germination (Windsor pers. comm). With the death of mature trees, the weedy woodland will proceed to S5 or S6 (T9 or T11). Erosion control efforts by the Soil Conservation Service in the 1960's returned most of the areas of S6 to S5 (T12) (Colclough, 1968). At this time there was some regeneration (S7), primarily Callitris but also dense patches of E. albens (T13). Following the

reintroduction of stock most of the S5 areas have stabilised. However, S7 is a transitional state, which may head towards an unforseen state (S8) that does not currently exist (T14).

Exotic weeds and increased nutrients create another asymmetric boundary (B2). White box seedlings, as well as some understory herbs and shrubs, may be inhibited by nutrients and compete poorly with exotic weeds (Windsor pers. comm.). Planting E. albens (if protected from grazing and weeded) can overcome the boundary for the overstory: however this is costly on a large scale and does not restore the understory. Removing topsoil has proven effective in some situations but has many drawbacks including erosion and cost.

Our experiments indicate that the identified boundaries are real, at least in the short term, and that removal of grazing by all herbivores may be necessary for restoration. Transplant data indicate that all herbivores cause mortality of seedlings, and that different herbivores affect species differently, thus controlling only stock may not allow understory recovery, even in the absence of other restoration boundaries. Based on the composition data, no fenced areas of S4 appear to be returning to S2, and no S2 areas are returning to S1. No grassland plots (S5) appear to be headed towards any woodland state. There was little E. albens recruitment, and that was seen only on exposed mineral soil in woodlands after drought breaking rain. No grazing sensitive species previously absent have appeared since fencing, and most germinates in the seed bank study were exotic weeds, with no species not recorded in the above ground vegetation recorded.

Further research is needed to confirm transitions and clarify the nature of the boundaries; however our model has helped identify three important problems in the restoration of White Box woodlands: nutrient enrichment, weeds, and loss of propagules. It also highlights the need to assess the condition of a remnant so appropriate restoration techniques can be applied. In most systems, particularly those with a complex history combining natural and anthropogenic events, the succession model is inappropriate and restoration based on this model is bound to fail. However, by understanding historical changes, which can determine a system's response to management, it may be possible to create an effective restoration plan.

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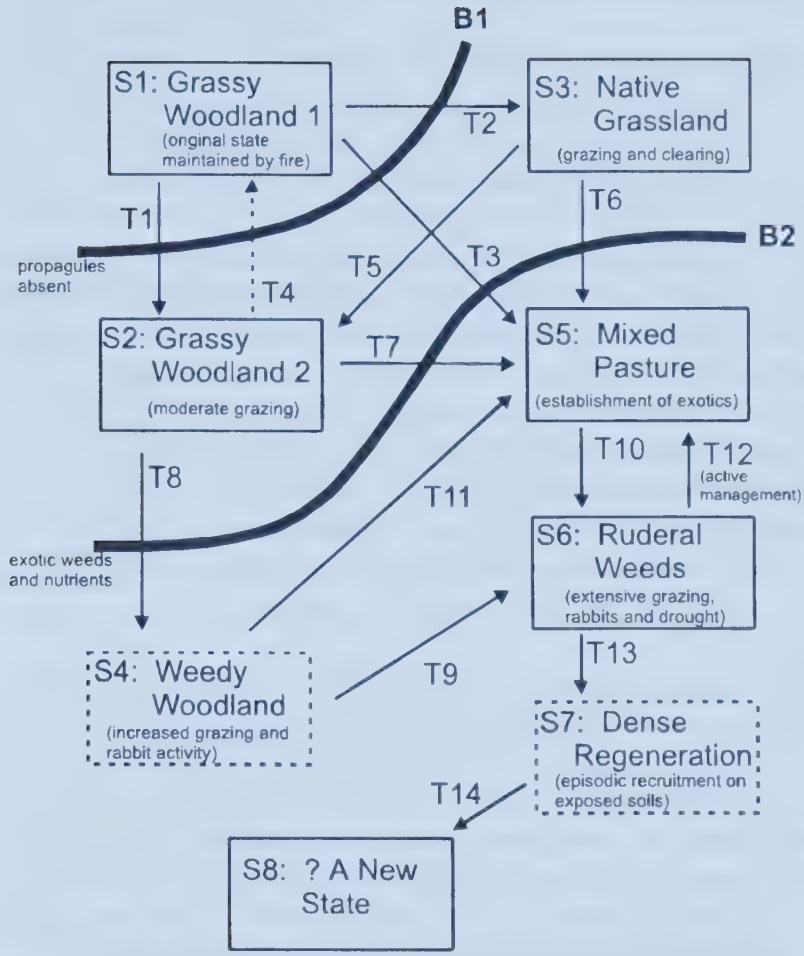

Fig 1. State and Transition Model for White Box Woodlands based on historical evidence and preliminary results of experimental studies. Solid boxes represent stable states. Dashed boxes represent transitional states. Arrows represent transitions. Bold lines represent asymmetric management boundaries. States, transitions and boundaries are further described in the text.

Ecosystem Based Management in El Salvador*

By James Ireland, Wayne Pepper and Flor de Maria Perla deAlfaro

Introduction:
Society has traditionally managed economic development independently from environmental and social concerns. When environmental or cultural concerns are raised about a particular economic development, changes have traditionally been made to modify the economic initiative on a piece-meal basis to prevent or mitigate environmental or social impacts. This environmental impact assessment process has had some success in reducing environmental and social damage but usually only on a local basis and at great economic expense. Often the mitigative targets have not been met for various reasons. Sometimes the environmental targets themselves failed to address basic problems. We now find that, despite society's efforts, environmental degradation continues, species numbers continue to decline, global climate change is becoming a serious problem and toxic materials continue to be introduced into the environment.

The El Salvador Connection:
ERIN Consulting, an environmental consulting company based in Regina, was asked to assist the Department of Environment and Renewable Resources in El Salvador to develop an Ecosystem Based Management Program. The country of El Salvador in Central America, faces many challenges resulting from having a very high human population density, a seriously degraded countryside, and a recent twelve-year civil war. Their major industry, coffee production and the need to feed and provide fuel for the high human population puts a severe strain on water supplies, soil productivity and air quality not to speak of the natural flora and fauna. ERIN Consulting is working with the El Salvadorian people to gradually clean up their environment without jeopardizing their fragile economy.

We have come to realize that, where humanity have such a major influence on the environment, an ecosystem based management program has to include humans as a major part of the ecosystem. Humans as a part of the world's natural flora and fauna are part of the basic ecological processes and functions in any region. In El Salvador, humans influences are everywhere. Demands on the environment to sustain human life influence all plans and actions by decision-makers. Consequentially, in accordance with the recommendations of the Bruntlund Report, the ecosystem based management process described here involves integrating environmental protection with economic development and social-political concerns.

We have identified the following basic principles to ecosystem based management:
Nothing can stand alone: everything is inter-related:

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A planned approach is needed;
Essential natural resources such as water, carbon, nitrogen and oxygen cannot be recreated only re-cycled;
Management decisions must be based on best information available;
All stack-holders should play a role in making decisions;
Decisions must consider the long term as well as short;
Decisions based on non-defendable information should be avoided..

Applying Basic Ecological Theory to Ecosystem Based Management:
Because all life depends upon adequate supplies of water, air, soil and functional biological diversity, ecosystem based management has to devise means of ensuring the critical processes and ecological functions which maintain these resources are sustained. If these vital processes disrupt the ecological cycles such as the water cycle, so called natural disasters such as drought or flooding result. In El Salvador, ERIN Consulting is assisting to decision-makers to gain a better understanding of the ecological processes, which are in greatest jeopardy. We will, having gained a greater understanding of the root cause of their environmental degradation, be better able to help them make improvements in their economic and social well being.

Designing an Effective Ecosystem Based Management Program:
We have suggested that a workable program needs a basic inventory of key parameters for measuring against, a monitoring system which measures changes from the normal (or the basic inventory), a problem identification capability and a problem solving capability. All this of course depends upon an effective and efficient information management system. This ecosystem based program requires substantial technical and people management skills to make it work. An initial approach to making ecosystem based management work for the people of El Salvador will be discussed.

Public Participation in a Multi-Stakeholder Process*

Mark Liskowich, Northern Mines Monitoring Secretariat

In 1995 Saskatchewan established three Environmental Quality Committees (EQCs) to increase 29 northern "impact Communities" input into decisions surrounding the development and operations of present and planned uranium mines. Supported by a Northern Mines Monitoring Secretariat (NMMS) of provincial and federal regulatory and developmental officials, some 75 community-nominated EQC representatives are increasing northerners' understanding of the industry and its regulation, and providing valuable perspectives and advice to government and industry on environmental, worker health and safety, and socio-economic impact issues. This innovative model of public participation in a multi-stakeholder process continues to gain national and international attention.

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Employment Futures: What does the Environmental Studies Students Association have to offer you?*

Margaret Wilson, President of the Environmental Studies Students Association,
Department Geography, University of Saskatchewan

The Environmental Studies Students Association is one of the largest mutli-displinary undergraduate student associations at the University of Saskatchewan. Our membership includes students from both the colleges of Arts & Science, and Agriculture. The primary theme of the Association is a concern for the environment, ranging from conservation, to academic studies, to recreational use, and especially of interest to our gathering today, professional affiliation.

Though our Association is open to all students, most of our membership comes from six related disciplines: Geography, Land Use and Environmental Studies, Regional and Urban Development, Environmental Earth Sciences, Agriculture Environmental Science, and Soil Science. The variety of disciplines within the Association is complimented by the interdisciplinary nature of those programs. Of the six, four are composite programs, with a broad base of topics covered, drawing instead from many departments. This allows those programs to cover a wider range of subjects. This diversity creates a wide range of flexibility. Our members are exposed to a variety of subjects, methodologies, and most importantly opinions and attitudes from related disciplines. This is the greatest strength our membership offers potential employers.

The Environmental Studies Students Association offers services to industry on two levels, as an organization and as individuals. As an organization it provides a three-way link between industry, students and the University. One of our main objectives has always been to promote communication between these three bodies. By working together we can design curricula that meets government and industry's need for trained professionals. Maintaining an open flow of information between the student body, university departments and industry is essential. All three, as well as society as a whole, benefit when university courses are designed to meet the needs of the corporate 'consumers' of graduates. As students we invest a huge amount of time, effort and money into our years at university. Our final goal is to find employment. The Environmental Studies Students Association promotes training and networking through social gatherings and organized volunteering opportunities

Organizations such as The Meewasin Valley Authority and The Canadian Wildlife Service have employed this facet of the Association to utilize student volunteers. The connections established by such activities benefit not only industry, but also provide tremendous opportunities for students to gain experience and contacts in industry. It must be noted that: university is not just about learning the facts, but about networking. These

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connections with peers and industry are the ties that carry an individual through the rest of his or her career. The Environmental Studies Students Association offers a bridge between industry and students entering the work force.

The environmental focus of the studies undertaken by the majority of our members is especially applicable to land reclamation. Many of the courses taught within our six main disciplines are directly related to the topics of this conference. While each of the programs has a slightly different focus, all are based in an understanding of the Scientific Method, and it's application to the physical world. The interrelationships between humans and the environment form the basis of the cirriculum. Students are trained in field and laboratory methods; the investigation and interpretation of the interface between the biosphere, atmosphere, lithosphere and hydrosphere; and the interaction of these with human behavior.

Geography, at the University of Saskatchewan, is divided into two main themes of Human and Physical Geography. These focus on the interrelations between place, space, humans, and change over time. Students are trained in field techniques, laboratory methods, and research skills. In addition to offering Bachelor degrees in Arts or Science, the department also offers Minor in Human, Physical, Urban Planning and Geographic Information Systems.

Both Agriculture Environmental Science and Environmental Earth Science are interdisciplinary programs with an environmental emphasis. The departments of Geography, Geological Sciences, and Soil Science administrate the Environmental Earth Science program. In addition to these three, core courses include biology and chemistry emphasizing the physical sciences. Agriculture Environmental Science focuses on an area of agricultural specialization, for example bioremediation or agricultural ecosystems.

Land use and Environmental Studies is jointly administered by the faculties of Geography, Sociology, Biology and Plant Science. This program trains students to investigate, analyze, research, and propose solutions to actual environmental management problems, while providing training in field research and reporting preparation.

Regional and Urban Development is an interdisciplinary program with components in Geography, Agriculture, Economics, Civil Engineering, Sociology and Political Studies. Students study the theory and practice of urban and regional planning by investigating the causes, impacts, and proposed solutions to community planning problems.

Of all the programs represented, Soil Science is the most closely link to land reclamation. Soil Science focuses especially on soils as the integrator of a broad range of environmental processes. Soil Science students learn about the physical, chemical, and biotic processes of pedogenesis; the response of soils to altered environmental conditions; and the structural and chemical properties of major soil components. The skills of soil survey, land evaluation, soil sampling, and chemical analysis are also part of the curriculum.

Both the Department of Geography and College of Agriculture run Co-operative Education programs. These programs allow students to gain valuable experience in their chosen field, while completing their education.

In closing, I would like to encourage all attending the conference to consider the benefits of becoming more involved wit student concerns. Take advantage of the opportunities available through the Co-operative Education program, through the Environmental Studies Students Association Career Day, and organized volunteering. More information can be obtained from the Department of Geography web site http://www.usask.ca/geography, the College of Agriculture web site http://www.ag.usask.ca, and the Environmental Studies Students Association web site http://www.arts.usask.ca/essa/, or do not hesitate to contact myself at mpw467@mail.usask.ca.

Yield and Nutrient Uptake of Wheat on Oil Well Sites: Effects of Topsoil Depth and Organic Amendments.*

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ABSTRACT

This study was conducted to determine the effect of different depths of topsoil replacement and organic amendments on the productivity of well sites. The experiment was initiated in 1997 on three oil well sites at Strathmore, Hesketh and Rosedale using a split-plot design with the depth of topsoil replacement as the main plot (0, 50%, 100% and 150% of recommended replacement depth). The subplot treatment was organic amendments: compost, fresh manure, alfalfa hay, wheat straw and a control as one-time applications in 1997. There was no effect of topsoil depth on grain yield, but yields from straw-amended plots were significantly lower than other amendments. Also topsoil depth did not influence nitrogen nutrition of wheat but phosphorus uptake was lower at the lower topsoil depths due to the tie-up of phosphorus by the subsoil. Alfalfa, compost and manure increased the nitrogen uptake of wheat, while compost and manure increased phosphorus uptake. The wheat straw amendment reduced both nitrogen and phosphorus uptake possibly via immobilization leading to a reduced yield. The results indicate that the application of topsoil is beneficial for crop growth but that diminishing returns set in at high topsoil replacement depths. A minimum topsoil replacement depth may be needed to prevent the negative impact of subsoil on P nutrition.

INTRODUCTION

An estimated 350,000 ha of land is leased in Alberta by the oil and gas industry for well sites, pipeline rights-of-way and plant sites. Approximately 40,000 ha of these becomes available each year for reclamation. Alberta Environmental Protection (AEP) requires restoration of specific levels of salvaged topsoil to wellsites before they are turned over to farmers or other land users. For wellsites constructed before 1983, AEP requires that 60 percent of the original depth of topsoil be replaced. The requirement is 70 percent for those constructed after 1983, and 80 percent for those built after April 30, 1994. Current regulations require topsoil to be salvaged and stored, but many older sites have little or no topsoil available for reclamation. In those cases, topsoil usually needs to be transported to the site, a practice that is expensive and can be limited by a lack of topsoil of suitable

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quality. In situations where sufficient topsoil is not available to meet the required replacement depth, application of amendments is recommended. While several amendments are mentioned in the guideline, there is no indication of the amount required to compensate for the shortfall of topsoil.

This three-year study was conducted to provide a baseline for substituting organic amendments for topsoil replacement. A knowledge of the appropriate depth of topsoil replacement and amounts of amendment needed to restore productivity to disturbed soil is important to the success of a reclamation exercise. With hard scientific data, AEP and industry will better be able to judge the effects of both topsoil and organic amendments on restoring soil productivity to wellsites. This could lead to more flexibility in the requirements and an overall improvement of reclamation practices."

The experiment was initiated in spring 1997 on three oil well sites at Strathmore, Hesketh and Rosedale. Preliminary results in the year of establishment was summarized by Klaassen et al (1998). Akinremi et al. (1999) provided information on the midseason biomass and yield in 1998. This report contains results of crop yield and nutirent uptake obtained in 1998 as influenced by depth of topsoil and orgainc ammendments

MATERIALS AND METHODS

Details of experimental design, research methodology and sampling techniques were provided previously (Klaassen et al.1998; Akinremi et al 1999). Briefly, the experiment was initiated in spring 1997 on three oil well sites at Strathmore, Hesketh and Rosedale using a split-plot design with depth of topsoil replacement as the main plot (0, 50%, 100% and 150% of recommended replacement depth). The subplot treatment was organic amendments: composted cattle manure, fresh cattle manure, alfalfa hay, wheat straw and a control as one-time applications in 1997. The plots were seeded to spring wheat in 1997 and 1998.

RESULTS

Grain Yield

Final harvest were obtained only at Strathmore and Rosedale as a result of the loss of the crop at Hesketh. Topsoil depth had no significant effect on grain yield, but the amendment effect was significant at the two sites in 1998 (Fig. 1). Crop on plots amended with wheat straw performed poorly and the treatment produced significantly lower yields than all other amendments including the check treatment (Fig. 1b). On average, yield from wheat straw amendment was about 50% of yields from other amendments at Strathmore and 66% of yields from other amendments at Rosedale. Grain yields from compost, manure and alfalfa hay were not significantly different from yield from the check treatment. Significant topsoil depth and amendment effects were obtained at mid-season (Akinremi et al. 1999) but this did not carry through to final harvest.

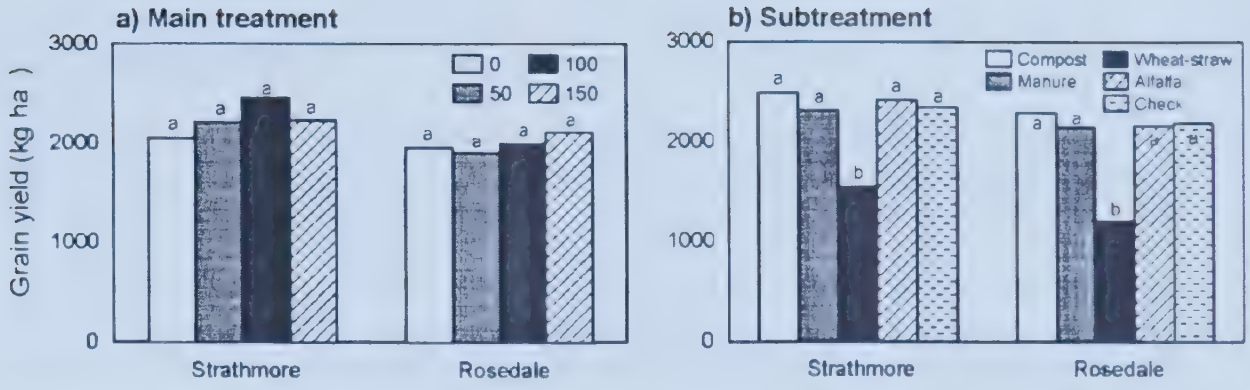

Figure 1. Means of grain yield by topsoil depth (a) and by amendment (b) in 1998. Means with the same letter are not significantly different (P<0.05).

Straw Yield

Straw yield was significantly affected by the topsoil depth and amendment at Strathmore and Rosedale in 1998 (Fig. 2). When averaged across amendments, the 100% topsoil depth produced the largest straw that was significantly different from the 0% depth (4262 versus 3080 kg ha^{-1}) at Strathmore. At Rosedale, both 100% and 150% topsoil depths produced straw yields that were significantly higher than the straw produced by the 0% depth.

When averaged across topsoil depths, straw yield from wheat straw-amended plot was significantly lower than yield from other amendments at Strathmore. Compost and alfalfa- amended plots produced significantly higher straw yields than the check plot. At Rosedale, wheat straw-amended plot produced straw yield that was significantly lower than other amendments but there was no significant difference between other organic amendments and the check treatment.

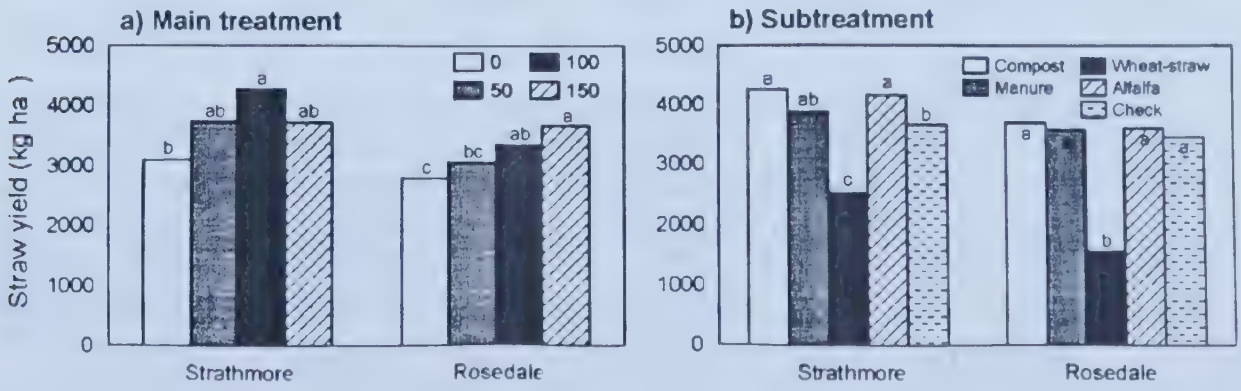

Figure 2. Means of straw yield by topsoil depth (a) and by amendment (b) in 1968. Means with the same letter are not significantly different (P<0.05).

Moisture Use Efficiency

Moisture use efficiencies (MUE) were calculated as a ratio of grain yield to moisture use during the growing season at Strathmore and Rosedale (Table 1). The MUE obtained in this study are comparable to those reported in previous studies (Larney et al, 1994). There was no significant effect of topsoil depth on MUE at any site. As well, no trend in MUE with increasing topsoil depth was apparent in 1998 at both sites.

There was a significant effect of amendment on MUE at both sites. Wheat straw-amended-plots used moisture less efficiently compared to other amendments. There was no significant difference between the MUE of other organic amendments and the check treatment, however, compost-amended plot had the highest MUE of about 16 kg ha^{-1} mm^{-1} at both sites.

Table 1. Moisture use efficiency (kg ha^{-1} mm^{-1}) in 1998

	Compost	Manure	Straw	Alfalfa	Check	Main-Plot
Strathmore - Site 1						
0	20.1	13.8	10.3	14.2	17.4	**15.2 a**
50	12.9	13.9	10.9	15.2	13.8	**13.3 a**
100	15.4	15.5	12.4	14.5	14.2	**14.4 a**
150	14.7	14.2	10.1	13.6	15.8	**13.7 a**
SUBPLOT	**15.8 a**	**14.4 ab**	**11.0 b**	**14.4 ab**	**15.3 ab**	
Rosedale - Site 3						
0	12.8	13.3	6.2	15.5	15.1	**12.6 a**
50	19.8	20.1	8	17.3	13.7	**15.8 a**
100	15.8	13.3	8	15.6	15.6	**13.6 a**
150	15.6	12.7	11	13.1	13.6	**13.2 a**
SUBPLOT	**16.0 a**	**14.8 a**	**8.3 b**	**15.4 a**	**14.5 a**	

Total Grain Nitrogen

The total grain nitrogen at Strathmore was higher than at Rosedale (Table 2) due to slightly higher yields (Fig 1a). There was no significant effect of topsoil depths on grain nitrogen at both sites in 1998. There was a significant effect of amendment on total grain N at both sites as the

Table 2. Total grain nitrogen (kg ha^{-1}) in 1998

	Compost	Manure	Straw	Alfalfa	Check	Main-Plot
-Strathmore - Site 1						
0	78	67	37	76	64	**64 a**
50	79	73	50	79	74	**71 a**
100	84	81	62	87	78	**78 a**
150	80	76	54	78	78	**73 a**
SUBPLOT	**81 a**	**74 a**	**51 b**	**80 a**	**74 a**	
Rosedale - Site 3						
0	72	63	26	72	72	**61 a**
50	72	73	27	66	59	**60 a**
100	75	64	37	75	73	**65 a**
150	75	70	55	80	72	**70 a**
SUBPLOT	**73 a**	**68 a**	**36 b**	**73 a**	**69 a**	

wheat straw-amended plots produced significantly lower N uptake than other treatments (Table 2). This is an indication of continued immobilization of nitrogen by the added wheat straw.

Total Straw Nitrogen

The effects of topsoil depth and amendments on total straw N in 1998 parallels their effects on total grain nitrogen (Tables 3 versus Table 2). Topsoil depth had a significant effect on total straw nitrogen only at Rosedale as the 150%, 100% and 50% topsoil depths produced significantly higher values than the 0% topsoil depth. There was a significant effect of amendments on total straw nitrogen at both sites with the superior amendment being alfalfa and the inferior treatment was wheat straw.

Table 3. Total wheat straw (kg ha^{-1}) in 1998

	Compost	Manure	Straw	Alfalfa	Check	Main-Plot
Strathmore - Site 1						
0	20	14	7	21	14	**15 a**
50	24	20	16	26	17	**21 a**
100	28	27	15	30	22	**24 a**
150	24	23	12	27	22	**21 a**
SUBPLOT	**24 ab**	**21 bc**	**12 d**	**26 a**	**19 c**	
Rosedale - Site 3						
0	17	14	5	17	17	**14 c**
50	22	18	5	24	17	**17 b**
100	22	19	7	23	21	**18 b**
150	28	25	11	30	18	**23 a**
SUBPLOT	**22 a**	**19 b**	**7 c**	**23 a**	**18 b**	

Total Grain Phosphorus

There was a significant effect of topsoil depth on total grain P at Strathmore where 40 kg ha^{-1} of P fertilizer was added with the 100% topsoil depth having significantly higher P than the 0% (Table 4). At Rosedale where no P was added, topsoil depth effect was not significant. Organic amendments had significant effect on total grain P with compost and manure producing significant higher P at Strathmore and compost at Rosedale (Table 4). Wheat straw-amended plots had the lowest total grain P in spite of a high P content indicating nutrient enrichment rather than the enhancement of P uptake on wheat straw-amended plot.

Total Straw Phosphorus

Similar to total grain P (Table 4a) there was a significant topsoil depth effect on total straw P at Strathmore (with added P fertilizer) but none at Rosedale. The 100% topsoil depth had a significant higher straw P than the 0% topsoil depth. The response of total straw P to organic amendments is similar to that of grain P. Compost and manure significantly increased the total straw P above that of wheat straw, alfalfa, and check treatments.

Table 4. Total grain phosphorus (kg ha^{-1}) in 1998

	Compost	Manure	Straw	Alfalfa	Check	Main-Plot
Strathmore - Site 1						
0	7.8	7.8	4.1	7	7	**6.7 b**
50	9.4	8.5	5.6	7.5	8.2	**7.9 ab**
100	9.2	9.8	7.3	9	8.3	**8.7 a**
150	8.7	8.5	6.2	7.6	7.8	**7.7 ab**
SUBPLOT	**8.8 a**	**8.6 a**	**5.8 c**	**7.8 b**	**7.8 b**	
Rosedale - Site 3						
0	8.1	7.9	3.4	6.8	7.8	**6.8 a**
50	8.6	7.9	3.5	6.4	6.2	**6.5 a**
100	8.7	7.2	4.3	6.8	7.1	**6.8 a**
150	8.5	7.8	6.4	7.4	7.6	**7.5 a**
SUBPLOT	**8.5 a**	**7.7 b**	**4.4 c**	**6.8 b**	**7.2 b**	

Table 5. Total straw phosphorus (kg ha^{-1}) in 1998

	Compost	Manure	Straw	Alfalfa	Check	Main-Plot
Strathmore - Site 1						
0	0.94	1.09	0.5	0.64	0.66	**0.77 b**
50	1.08	1.11	0.99	0.89	0.7	**0.95 ab**
100	1.87	1.65	0.99	1.28	0.99	**1.36 a**
150	1.46	1.32	0.89	1.1	0.93	**1.14 ab**
SUBPLOT	**1.34 a**	**1.29 a**	**0.84 b**	**0.97 b**	**0.82 b**	
Rosedale - Site 3						
0	1.26	1.18	0.91	0.68	0.8	**0.97 a**
50	1.94	1.42	0.98	0.99	1.04	**1.27 a**
100	1.68	1.73	0.91	1.08	0.85	**1.25 a**
150	1.8	1.8	1.07	1.29	0.83	**1.39 a**
SUBPLOT	**1.71 a**	**1.53 b**	**0.97 b**	**1.01 b**	**0.88 b**	

SUMMARY

The results obtained in 1998 show that treatment effect not only depends on the site but also on the time of sampling due to the modifying effect of available soil moisture and rainfall pattern. The topsoil depth did not influence nitrogen nutrition of wheat but phosphorus uptake was lower at the lower topsoil depths possibly due to the tie-up of phosphorus by the subsoil. The significant topsoil effects were found at Strathmore where supplemental amount of P was added and not at Rosedale where fertilizer P was not added in 1998. Alfalfa, compost and manure increased the nitrogen uptake of wheat, while compost and manure increased phosphorus uptake. The wheat straw amendment reduced both nitrogen and phosphorus uptake possibly via immobilization leading to a reduced yield.

The results indicate that the application of topsoil is beneficial for crop growth but that diminishing returns set in at high topsoil replacement depths. The biggest "bang for the buck" appears to be the first topsoil depth increment after which gains from increasing topsoil diminish. Of the organic amendments, compost appears to be superior followed closely by alfalfa hay and manure.

ACKNOWLEDGEMENTS

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Remediation of Potash Slime Tails Through Use of Cross-Linked Polyacrylamide Hydrogel*

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1.0 Introduction

Approximately 300 million years ago, during the Pliocene series of the Tertiary period, the earth went through a substantial global cooling trend. The mean annual temperature during the Pliocene, along the coast of the pacific coast of North America, was 12 ° C (Goudie, A. 1992). Sea levels markedly lowered as the water was frozen into glaciers, and there were mass flora and fauna extinctions. Oceanic salinity levels rose as a result of the glaciers formation thereby precipitating out the ocean salts. During one of the glaciation cycles of the Pliocene, the Devonian, a great inland ocean, covering a substantial portion of northern North America, evaporated and/or was taken up by the proceeding glaciers leaving behind mass deposits of Na-K-Ca-Mg Cl salts. It is from these salts, located within the Elk Point Basin region of the Williston Basin, that potash is mined from. As the ocean filled in and dried up, it was eventually covered by more than a thousand meters of cover material. 1.2 km below the surface of the earth at Vanscoy, SK, lies a substantial deposit of potash contained within an extremely saline marine sediment. During the course of the mining and separation process, potash mine slime tails, a combination of silt (36-38%), clay (27%), and sand (10%) particles, high in Na (≅ 48,000 mg/L), K (≅ 24,000 mg/L), Ca (≅ 1,920 mg/L), Mg (≅ 110 mg/L), and carbonates (26-28%), settles out into large ponds. The pH of the marine sediment, 7.7 to 8, is neutral to slightly alkaline, however the electrical conductivity is approximately double that of sea water, easily surpassing EC values of 200 mS cm^{-1}.

Decommissioning of the potash mining sites requires that the slime tailings be reclaimed. A number of tactics have been tried to date with negligible success. In 1996 a greenhouse study using the soil amendment cross-linked polyacrylamide hydrogel (X-LPAM) was tested to determine if it could be used to create soil structure thereby allowing the slime, or marine sediment, to be leached of its high salt load. The greenhouse study indicated that the 0.2% (polymer wt./soil wt.) addition of X-LPAM was the most successful in reclamation of the sediment. Three different types of grasses (*Puccinellia distans*, *Agropyron smithii* and *trachycaulum*), were successfully germinated and grown. The 0.2% polymer treatment had the highest efficacy, and in decreasing order of efficacy, 0.3%, 0.1% and then the control with no polymer. The experiment showed that the level of SAR (Fig. 1.0), EC, and bioavailable sodium concentrations, which were originally 61, 189 mS cm^{-1}, and 2050 µg 10 cm^{-2} hr^{-1} respectively, dropped to 1, 4 mS cm^{-1}, and 41 µg 10 cm^{-2} hr^{-1} respectively, in the 0.2% (polymer wt./soil wt.) treatment. Due to these results, the decision by the potash industry, SERM, and SnF Floerger (the company

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supplying the polymer), was to try a field experiment to see if these positive results could be replicated under field conditions. For reference purposes, halophytes are capable of growing in soils with an EC of between 30 and 50 mS cm^{-1}, i.e. *Distichlis stricta* and *Salicornia rubra* respectively (Tiku, B. 1975), and SAR > 13.

A site was chosen at the Agrium mine located at Vanscoy, SK, and a raised bed was constructed in early summer 1997. Due to regulatory delays the research project was unable to get underway until July of 1998. At this time the raised bed was amended with the polymer treatments, and leaching began by mid-August. There were seven leachings with city of Saskatoon treated water, of approximately one inch per leach. Leaching was completed for the year on September 25. N and P fertilizer was added on October 5, sediment samples were taken October 20, to determine the success of the summers leaching, and seeding commenced with *Puccinellia distans, Agropyron smithii* and *trachycaulum,* and was completed by October 21. Results of the soil analysis indicated that there was a significant decrease in the level of salts contamination, however there was no significant treatment effect. There was evidence that the polymer had sequestered salt during the course of the leaching. There was also evidence of a 'locational effect', within the raised bed, which appeared to be the result of the water table depth within the slime tailings holding facility. This factor was confirmed during the summer of 1999 sediment sampling. Benchtop studies done during 1998-9 also confirmed that polymer treatments had little significant effect on leaching. It was confirmed that the polymer appeared to sequester the salts and gradually release them during the leaching process, whereas the control, with no polymer addition, was able to successfully leach salts as long as drainage was available.

Due to recontamination of the site during late 1998 and during the 1999 growing season, as a result of a substantial rise in the water table, cores were taken from cells containing *Puccinellia distans*. The other two grasses, *Agropyron smithii* and *trachycaulum*, had lost seed viability and were therefore excluded from the remainder of the experiment. The soil cores were put into a growth chamber and leached with 1.5 inches of distilled water per leach. The goal of this alteration in the research experiment was to determine if germination of the *Puccinellia* was possible under lower EC conditions, and if so, at what eluate and soil EC it would occur, and how much leaching water would be required to achieve this. After only 4 leachings germination occurred in two of the control cores which had visibly slower infiltration rates than most other cores, especially the cores containing polymer. Sediment containing hydrated polymer has a visibly looser soil structure and water infiltrates very quickly.

How did this growth chamber experiment differ from that of the greenhouse? Why the conflicting results between the greenhouse, growth chamber, and field experiments? One factor that was evident in both the greenhouse and the two growth chamber experiment results was very rapid water movement through many of the cores or pots. During the greenhouse experiment, a delay period near the beginning of the experiment, where no water was added, apparently caused substantial internal drying of the treatments and shrinkage. This enabled water to move down the sides of the control pots, instead of

through the sediment, whereas those pots which were amended with polymer, having an extra water store in the polymer, were delayed in their shrinkage depending on the level of polymer added. Any shrinkage which did occur within the polymer treatments appeared to allow water to pool around the polymer where it was soon soaked up and which thereby caused expansion of the sediment/polymer mix in the pot. It is hypothesized that the added water storage of the polymer prevented the same effect of shrinkage as what occurred in the control pots, and thereby promoted greater downward movement through the sediment itself, removing greater amounts of salt. If a barrier could have been placed down the sides of the pots, thereby preventing water from escaping down and out the sides of the pots, it is hypothesized that the same effect as what was seen in the growth chamber and benchtop experiments would have occurred.

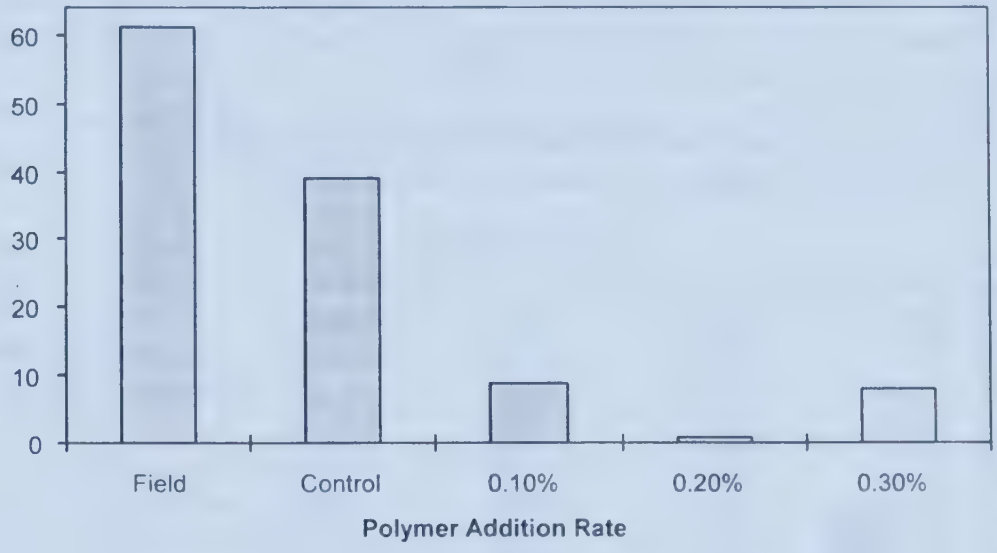

Figure 1.0 SAR Treatment Comparison, Using Saturated Pastes, of a Greenhouse Experiment on Potash Mine Slime Tailings

Figure 2.0 shows effective leaching in all treatments of the raised bed over time when comparing with the compacted walkway, contained in the raised bed, and with the perimeter, in the tailings, samplings. There appears to be a significant drop in EC values in all treatments when comparing the summer and fall 1998 samplings. The increase in EC noted in the summer 1999 samplings, caused by the rise in the tailings water table, appears to exert a greater effect in the polymer treatments. It is in these treatments that the rise in EC is more substantial, especially in the 0.3% polymer addition treatment.

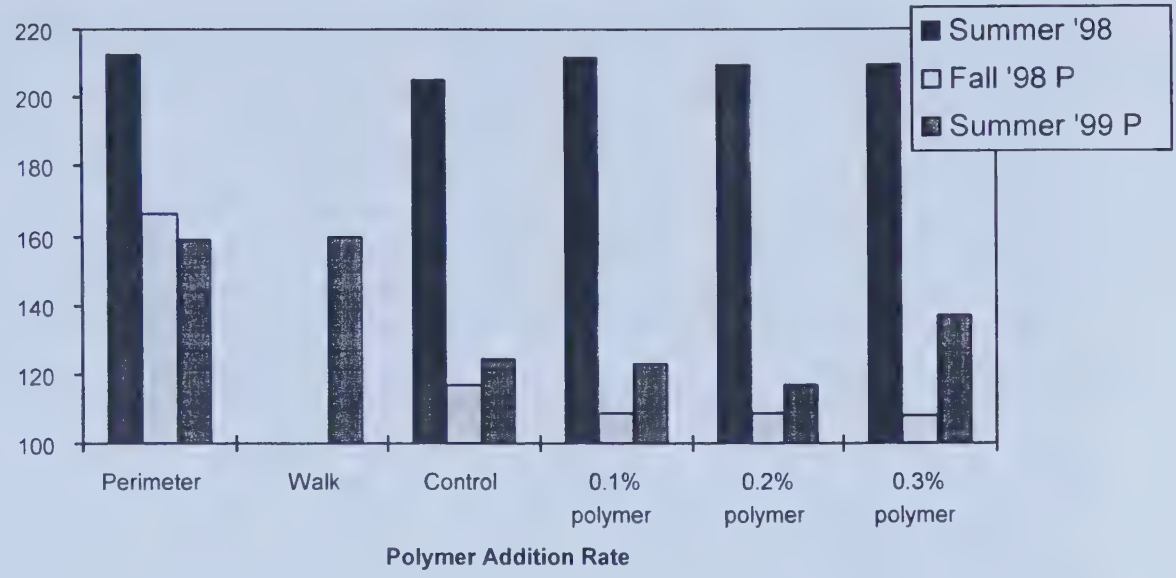

Figure 2.0 Comparison of Treatments Over Time Using Saturated Pastes of Potash Mine Slime Tailings

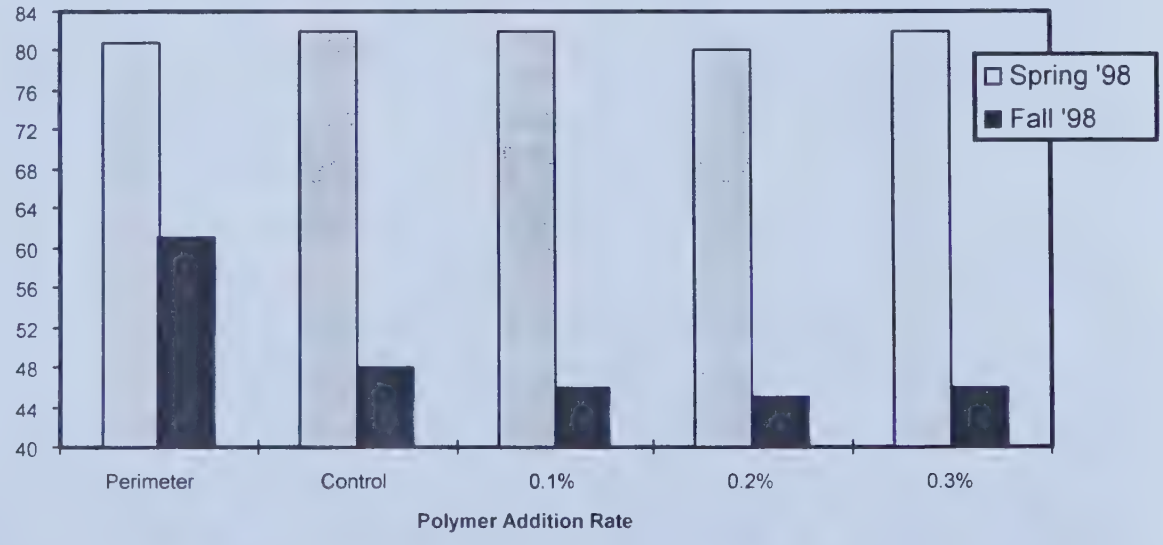

Figure 3.0 Comparison, Using Saturated Paste Analysis, of SAR Values for the Potash Mine Slime Tails Spring and Fall 1998 Samplings

SAR values in Figure 3.0 indicate, as do the EC values in Figure 2.0, effective sodium salt leaching between the summer and fall 1998 tailings samplings. The effective decline in SAR values lie between a 40 and 50 % decline in SAR values with only a couple months of leaching. This is extremely positive data indicating that these tailings could be effectively leached quite quickly assuming adequate drainage was provided.

3.0 Conclusions

In conclusion, it is the opinion of the author, that the potash mine slime tailings, located at Vanscoy, SK, could be successfully reclaimed with adequate drainage, i.e. a substantial lowering of the water table in the tailings holding facility, and sufficient leaching of salts out of the system, i.e. through irrigation with good quality water and removal of the leachate from the area. Although polymer does exert a positive effect regarding decreasing surface evaporation, providing a more stable surface, i.e. decrease in erosion, and providing a looser soil structure, its ability to sequester cations, which are released over time, reduces its effective use in leaching salts and reclaiming the potash mine slime tailings located at Vanscoy, SK. The polymer may be more effective in soils containing appreciably higher percentages of clay where compaction may be a greater threat to effective leaching, or in tailings where erosion may pose a threat to the protective dikes, i.e. polymer sprayed on the surface for surface stabilization. The soil textural qualities, i.e. silty clay (Pierzynski, et al. 1994), of the tailings from the Agrium site, permit effective leaching of the salts under adequate drainage conditions and polymer addition appears to delay this leaching process.

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Fifteen Years of Subsoil / Mine Spoil Development in Constructed Profiles of Varying Subsoil Thickness. *

D.L.Bailey, and D.J.Pluth, University of Alberta and Cam Bateman from Trans Alta.

Subsoiling is an acceptable practice towards the reclamation of salt affected mine spoils. Placement of soil material of varying thickness over spoil influences soil genesis and soil capability for agricultural cropping. This study examines the differences in subsurface characteristics of two types of constructed profiles: 0.55 m and 0.95 m of a mixture of B and C horizon material (subsoil). The silty clay subsoil (SAR=0.7, EC=0.5 dSm^{-1}) was placed over a sandy clay mine spoil (SAR=20.1, EC=1.9 dS/m^{-1}). Both profile types were topped by 15 cm of clay loam A horizon luvisolic material. Each profile was constructed into a 8 x 20 m plot with three replicates. Subsoil bulk densities (Db) averaged 1.6 Mgm^{-3} ± 0.12 (SD) in the 0.55 m profile and 1.56 Mgm^{-3} ± 0.07 (SD) in the 0.95 m profile. Mine spoil Db averaged 1.84 Mgm^{-3} ± 0.08 (SD)(0.55 m) and 1.76 Mgm^{-3} ± 0.16 (SD)(0.95 m). The two profiles exhibit a similar trend in volumetric water content with depth regardless of time. Volumetric soil water (θv) increases from the topsoil to shallow subsoil, however, drops with depth in the subsoil before increasing again in the spoil material. As well, at any depth θv values were greater in the 0.55 m profile.

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Setting Reclamation Standards: When is Soil Decompacted?*

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Abstract:

Many reclamation sites are associated with compacted soils. Compaction is defined as an increase in bulk density or a decrease in total porosity. The cause of compaction is usually machine traffic. Normally, reclamation is considered to be complete only when compacted soil has regained its natural or undisturbed porosity (or bulk density value). But what is the "control" soil? Nearby soils may have different particle size distributions or more organic matter than the compacted soil, both of which change porosity and bulk density. Also, nearby soils may have undergone previous compaction while appearing to be undisturbed at present. In neither case would nearby soils represent a "control" or undisturbed comparison. Furthermore, at what water content should porosity or bulk density be measured? Soils that shrink and swell change porosity and bulk density with a gain or loss of water.

In this paper I outline a new method for describing the porosity and bulk density of compacted soils and the "control" to which they should be compared. I show that the compacted soil itself can be processed in the laboratory so that it regains a natural structure, representing an undisturbed porosity or bulk density. And I list the required measurements for describing porosity and bulk density of any soil under any condition.

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Papers
Received
at
Conference

Soil Information Resources for the Prairies: The Saskatchewan Soil Resource Database

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1. Introduction

This paper will provide the reader with the present status of the Saskatchewan Soil Resource Database as well as some background on the processes in developing a comprehensive soil resource database for the province. Although the title of this presentation indicated Soil Information Resources for the Prairies, I will be restricting my presentation to the Saskatchewan Soil Resource Database. Soil resource information for Alberta, Saskatchewan and Manitoba can be obtained by contacting the agencies listed at the back of this paper.

2. Saskatchewan Soil Survey

The first broad soil information coverage for the agricultural area of Saskatchewan was realized with the publication of the No. 12 Soil Survey Report in 1944 which covered the agricultural area of the province from the 49th parallel up to and including Township 48. The agricultural area of the province north of Township 48 was covered by the No. 13 Soil Survey Report which was published in 1950. It was soon realized that more detailed soil resource data was required for a variety of applications, and there was a need to better classify and organize soil resource information by applying the new National system of soil classification to the soils in Saskatchewan. A semi-detailed soil survey of the agricultural area of the province started in 1958 with soil mapping in Regina map sheet area. Over a period of 38 years from 1958 until 1996, the agricultural area of the province was re-mapped at a semi-detailed scale by the Saskatchewan Soil Survey; the Saskatchewan Soil Survey was composed of staff funded by the province and also by staff funded by Agriculture and Agri-Food Canada, all working cooperatively out of the University of Saskatchewan to provide soil resource data to the public. The focus of the Saskatchewan Soil Survey has primarily been to map the location and extent of the different soil types in the province, and to compile this information into map format to show the distribution of the different soil types and to produce accompanying soil reports to describe the nature and properties of the soils encountered. Since about 1980, an emphasis was placed on collecting more information and providing a wide range of interpretations. Research in Soil Genesis, Soil Quality, establishment of Benchmark Sites for monitoring changes in soil quality, soil transects, and support of graduate programs are other activities that have all added to the body of knowledge about the province's soil resources.

3. Saskatchewan Land Resource Centre

The cooperative relationship and work by provincially-funded and federally-funded personnel continues today, but rather under the Saskatchewan Land Resource Centre (SLRC). The focus has shifted markedly from data gathering: the immediate focus now is creation of a seamless soil resource database for the province that is suitable for use at a scale of 1:100,000. Soil Survey

evolved over the 38 years, with new concepts in soil mapping, soil information being presented in somewhat different formats, and increasingly greater amounts of information being collected. The late 1970's and early 1980's saw the computerization of the soil data which greatly facilitated the task of storing and managing a large and ever-increasing soil polygon and attribute database; management of the soil resource database is accomplished in a Geographic Information System environment. The Saskatchewan Soil Resource Database is a large database. There are in excess of 80,000 soil polygons with 13 attributes being available for each soil polygon in map sheet areas and 19 attributes being available for each soil polygon in R.M. map areas. Over the last several years, soil information has been attached or digitized to 1:50,000 scale digital base maps. The Saskatchewan Land Resource Centre and P.F.R.A. are cooperating through the Soil Conflation Project, which has as it's goal, to match all 1:100,000 soil line data to 1:50,000 digital base maps, and to create a continuous and standardized, seamless soil line and attribute coverage for all of the agricultural area of the province; the digital base maps are considered the provincial standard and are supplied by SaskGeomatics, Regina, Saskatchewan. At the end of this project there will be no artificial boundaries such as R.M. boundaries or NTS map sheet boundaries. This project has involved a significant amount of re-digitizing of soil lines, particularly for those R.M.'s that occurred in former soil reports defined as map sheet areas, as well as adjustment of soil lines along sharp topographic breaks and along hydrographic features. The SLRC is now in the stage of making final corrections to line work.

Other important goals of the SLRC are to provide effective management and update of the seamless soil resource database, to establish the infrastructure to ensure long-term and effective access to soil information, to promote and illustrate the utility of the data for making sound decisions about use and management of our soil resources, and to provide effective client consultations to understand, interpret and utilize the data.

4. Soil Mapping in Saskatchewan

From 1958 to about 1978, soil mapping was on a map sheet basis (an area defined by a 1:250,000 map sheet); from 1978 to 1996, mapping was done on an R.M. basis. Approximately 60% of the agricultural area of the province has been mapped on an R.M. basis with the other 40% being mapped on a map sheet basis. Those areas mapped on a mapsheet basis include Regina, Willow Bunch Lake, Rosetown, Swift Current, Weyburn-Virden, Saskatoon and Hudson Bay.

5. Comparison of Map Sheet and R.M. format databases

Map sheet maps have evolved over the years with data being presented in different formats. In consideration of developing a seamless soil resource database, a Unified legend was developed for all map sheet areas; this involved numerous conversions, with the structure of the R.M. database being the template. Data in all fields in the map sheet database have been converted to the same format as the R.M. database. As an example, in the map sheet areas, two or three soil associations would typically be listed for a soil polygon: this has been trimmed to a two association complex: this is not to say that more than two associations may be listed in the soil description, however, only two soil associations are listed in a map unit. Given that there has been numerous conversions of map sheet attribute data to R.M. format, descriptions for new soil

association complexes, in particular, will have to be created to support the new standardized format for map sheet areas. R.M. format maps have had significantly more data attached to them, particularly interpretations, and this has required updating the map sheet database to near the level of the R.M. database. Fields that have been updated in the map sheet database include agricultural capability, surface pH, salinity, and irrigation suitability; those fields yet to be updated include potential Wind and Water Erosion. Certain data was not collected in some or all of the map sheet areas: this includes slope length, past wind and water erosion, stones, salinity, and wetland information. Salinity was derived from assessment data for map sheet soil areas: it consists of a single character code, and all salinity is assumed moderate... the best that can be done without going out into the field.

6. Soil Resource Data Formats

Information that is presently available from the Saskatchewan Land Resource Centre includes:

1. Hard Copy: soil maps and reports exist in somewhat different formats for all agricultural areas of the province, at scales of 1:126,720, 1:125,000, and 1:100,000.
2. Electronic Format: it is estimated that the soil conflation project will not be completed until about the end of June 2000. Digital soil line data as well as accompanying attribute information is available for all agricultural areas of the province, although until the soil conflation project is finished in 2000, the original or non-conflated data will be supplied to clients; data supplied for map sheet areas will not include the new fields of information. The original digital data supplied at present is georeferenced, but is not matched to the 1:50,000 digital base map as is the new conflated data. The original digital data fits together fairly well in most areas, but will not be comparable with the fit of the conflated data to the 1:50,000 digital base map. The non-conflated data will occur in UTM Zone 12, 13 or 14, whereas the conflated data will fall into an extended Zone 13. The datum for both at present is NAD27.

7. Release and Distribution of Digital Soil Resource Data

There is a rather simple release policy at present: data is for the use of the original purchaser, is not to be sold to a different client, and the Saskatchewan Land Resource Centre shall be acknowledged as the supplier of the digital soil data in project maps created by clients. The SLRC is the sole vendor of the original digital soil information. A memorandum of understanding exists with SaskGeomatics that they will sell the conflated soil line data.

8. Pricing of Soil Resource Data

At present, the cost of digital soil data is related only to the time it takes to extract and process the data, to transfer the data to a CD, and provide some minor explanations for the client.

To obtain Soil Resource Information for the Prairies please contact the respective agency for each province.

In Saskatchewan:

Saskatchewan Land Resource Centre
G.A. Padbury, Section Head
5C26 Agriculture Bldg
51 Campus Drive, U. of S.
Saskatoon, Sask. S7N 5A8
Ph: (306) 975-4060 FAX: (306) 966-4226
E-mail: landinfo@digger.usask.ca

In Alberta:

Conservation and Development Branch
Attn: Mr Tony Breirley
Alberta Agriculture, Food and Rural Development
#206 O'Donoghue Building
7000 - 113 Street
Edmonton, Alberta T6H 5T6
Ph: (780) 427-3781 FAX: (780) 422-0474

In Manitoba:

Manitoba Land Resource Unit
R.G. Eilers, Unit Head
Room 362 Ellis Bldg., Univ of Manitoba
Winnipeg, Manitoba R3T 2N2
Ph: (204) 474-6118 FAX: (204) 474-7633

Cameco, Key Lake Regreening Project, in Harmony with Nature (1978-1999 & beyond)

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Abstract: Cameco, Key Lake Operation is located in North-Central Saskatchewan, on the southern boundaries of Athabasca formation. Exploration in the early seventies led to the discovery, development and mining (1982-1997) of two uranium ore bodies, the Gaertner and Deilmann pits. The regreening of the disturbed areas at Key Lake started in late seventies when numerous experimental plots were set up to study the establishment and survival of various agronomic species and their adaptability to the harsh environmental conditions in the Athabasca Region of northern Saskatchewan.

The objectives of the initial program were to: reduce soil erosion and dusting, rebuild the top layer and improve aesthetics. Most of these objectives were achieved by the development of a small annual hydroseeding program that stabilized the high traffic areas and slopes of embankment areas such as reservoirs and tailing pond. However, the ultimate goal of reclamation is to return the land to a self-sustaining state similar to its pre development state. The existing program was found unsustainable, and as a result, in 1993 Cameco augmented its previous research activities to enhance the long-term viability of the revegetation program. Various native grasses, shrubs and trees were cloned and transplanted in the nursery, planted in experimental plots, and studied over a five-year period. This led to the successful planting of nearly half a million jack pine seedlings native to Key Lake, the establishment of two native grass seed farms, the development of a five-year plan and changing the status of about 165 hectares of disturbed land too undisturbed.

By 1996, a methodology was also developed for regreening flat areas where a disturbed area could successfully be stabilized and tree-planted within the same year which led to the development of a five-year revegetation plan. However, the methodology applied to flat areas may not necessarily be applicable to large sloped areas ie, waste rock piles. In 1998, various sloped areas were identified and a research program developed and applied to the slopes. The objective of the program was to identify factors affecting soil erosion and stabilization on the slopes. In July of that same year, Key Lake experienced a one in a one-hundred-year storm event which washed away many of the research plots established earlier in the year, thereby proving that surface erosion may not be the only issue on the slope areas.

To date, research and experiences gained, indicate that the best method to stabilize a site is to follow a methodology which is similar to the pattern in nature and utilize native species from the surrounding area. To enhance the process, native or imported pioneering species capable of stabilizing and paving the way for the climax species must be used. The research also indicates that even though the slope areas pose similar challenges as the flat areas, the issue of erosion control on slopes is far more complex than on flat areas.

1.0 INTRODUCTION

The concept of ecological succession leading to the stable steady-state vegetation (climax) of a disturbed site such as mining has been well documented. However, since the reclamation specialist has to deal with numerous and often competing site specific factors, he or she has to use experiments to test the nature of the site and what works best. In other words, reclamation could be and often is site specific. To identify the most adaptable species and economical method of reclaiming the disturbed sites at Key Lake, numerous experimental plots between 1978 and 1986 were set up and studied. The present hydroseeding program is partially the result of these studies. However, due to competing priorities for a limited manpower, not all the results were properly documented. Also, at times many variables were changed at the same time, making it difficult to interpret the results. Therefore, in 1993, Key Lake Operation augmented its research program to include pioneer and climax species and the relation between the two.

The new research program had two arms - the laboratory program, where scientific research was performed on actual plants from the site and the field program, where various pioneer species and jack pine seedlings (the predominant climax species) were studied under site conditions. The study started in 1993 and ended in 1997. The result was the development of a process that has proven successful to reclaim flat areas of the site. The most important factors affecting the survival of plants regardless of species are the genetic of the species and the damage due to wind erosion. Therefore, if the plants are properly selected and wind erosion eliminated, the growth rate of plant would depend on other factors such as nutrient availability which are relatively easier tasks to perform.

After successful development of the above methodology the research team focussed its attention on the development of a proven methodology to reclaim the slope areas, such as the slopes of waste rock piles and river crossings and large trenches. As a result, in 1998 a research program was established to study various factors on sloped areas. This program is ongoing.

1.1 Background

Key Lake Operation is a joint venture between Cameco Corporation and Cogema Resources. It is located in north-central Saskatchewan, about 70 km east-southeast of Cree Lake (Figure 1) at an approximate latitude of 57°11' north and longitude of 105°34' west. It lies within the southern boundary of the Athabasca basin, a geological formation composed of flat lying pre-Cambrian sediments (mainly sand and granules). The glacial erosion of this material left a landscape composed largely of nutrient poor sandy material.

The project started in 1982 with the open pit mining of Gaertner ore body which was mined out in 1987. The open pit mining of Deilmann ore body commenced in 1986 and was completed in 1997. The milling activities of Deilmann ore are expected to continue until early 2000.

As a result of the mining activities, close to 1,000 hectares of land has been disturbed which requires reclamation. This includes the building sites, Tailings Management Facilities, the reservoirs, monitoring ponds, the airport, the roadways, waste rock piles, lay down areas, the borrow pits, the residential camp, etc.

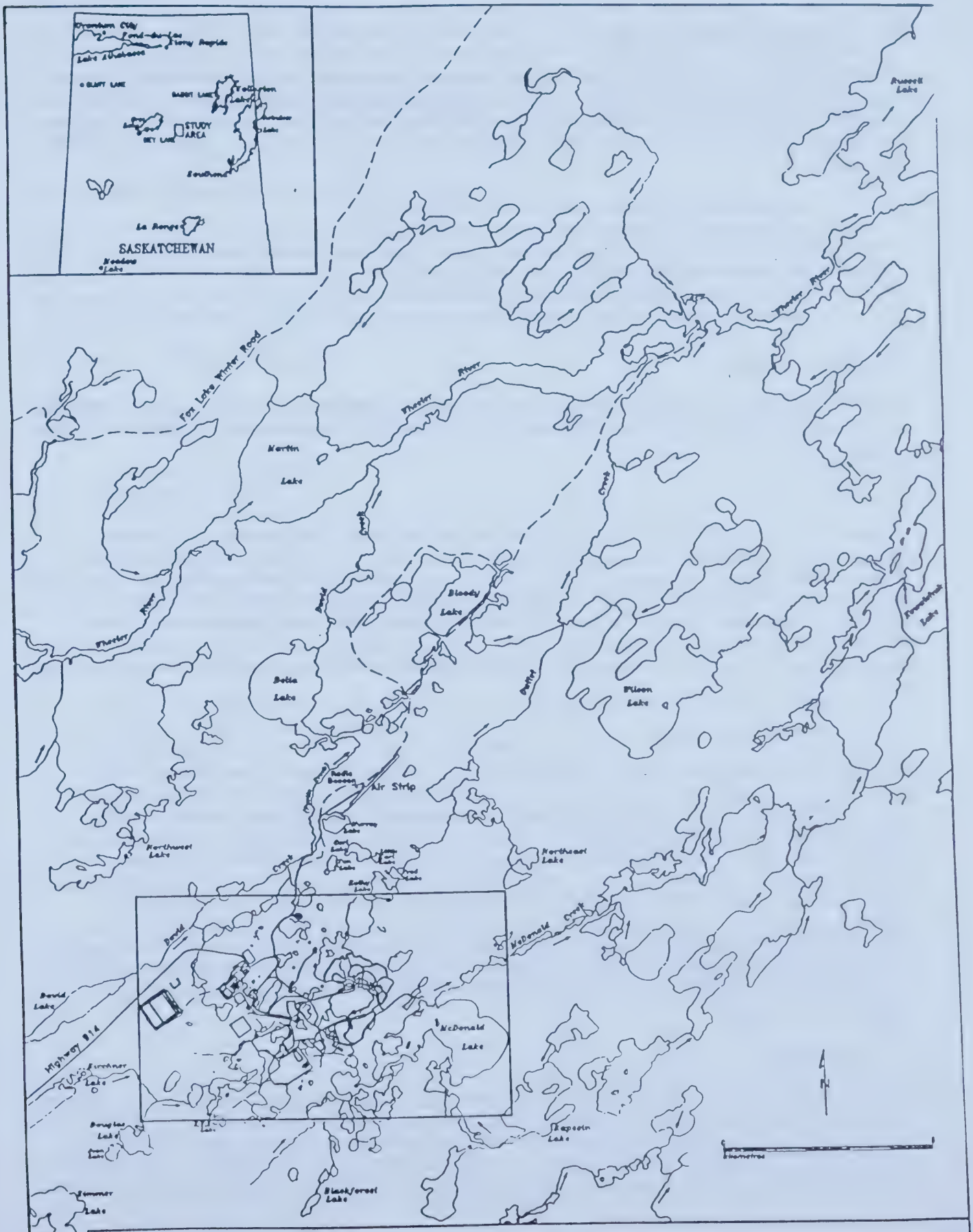

FIGURE 1. Study area and study location.

2.0 Objectives of the Program

The overall objective of the program is best described in the Key Lake five-year revegetation plan as "To return disturbed areas of the Key Lake mine site, to a stable, vegetated state, similar to the pre mining era, through the development of a mosaic of habitat types and erosion control techniques, to enhance the establishment of long-term natural vegetation" social and economic considerations taken into account. However, the specific objectives of the program are to:

- Identify the species most suitable to the conditions of the site.
- Utilize as much as possible species native to Key Lake area.
- Harvest seeds that are native to Key Lake through establishment of seed farms.
- Develop a methodology to revegetate the flat and slope areas.
- Develop a criteria for the revegetation of disturbed sites.
- Satisfy Cameco's license requirements as far as reclamation at Key Lake is concerned.

3.0 Site Description

There are many features of a site that directly impact the reclamation/revegetation of disturbed areas. The following is a brief description of various features of Key Lake site that determine plant species native to Key Lake and their growth rates.

3.1 Soil

There are five types of soil identified in the Key Lake area, i.e., till, glaciofluvial, eolian Sand, slope wash, and organic deposits. Soils, where developed, are thin and underlain mostly by sand, well-drained and exhibit low moisture-holding capacity. As a result, the Key Lake area is unsuitable for agriculture or pasture land. All mineral soils at Key Lake area have low nutrient status, Cation Exchange Capacity (CEC), pH, and Electrical conductivity (EC) and are classified as sand textured. As a result, these materials are considered poor media for revegetation. The organic soils (associated with muskeg and riparian areas) have significantly higher nutrient contents, CEC and moisture, but lower pH than mineral soils and are considered better media for revegetation. However, they are very scarce.

3.2 Climate and Meteorology

Key Lake lies within the Boreal climatic zone, which covers Canada from Alaska to Newfoundland. Boreal climates are influenced by cold arctic air masses causing long and frigid winters and cool, moist northern pacific air masses which enter the region during generally short and cool summers. The Key Lake climate, therefore, is characterized by short, cool, moist summers with a mean monthly temperature of 15.85°C in the warmest month (July) and long, cold winters with a mean monthly temperature of -23.21°C in the coldest month January. Temperature extremes of mean monthly temperatures are typical of northern Saskatchewan. The total annual precipitation has averaged 457.36mm over the 1977 to 1998 period with 66.86% of the precipitation falling predominantly as rain over the summer months. The average pan evaporation rate over the same period was 652.93mm (Annual Report, 1998). Average annual wind speed in the region is less than 16 km/hr, with maximum speeds between April and October, and relatively calm periods during winter which reduce the incidence of extreme wind chill conditions. Winds from the west quadrant (SW-W-NW) and north quadrant (NW-N-NE) predominate (TAEM & SENES, 1994).

3.3 Vegetation

Vegetative cover in the Key Lake area is generally a function of landform. There are two general vegetation types - 1) Forest type and 2) wetland type. The forest type occupies a well drained, treed upland sites whereas the wetland type occurs in poorly drained peat or sedge lowland sites. The vegetation cover at Key Lake is almost entirely of jack pine, with only small patches of Black Spruce. Jack pine forests are found on upland areas with coarse textured soil. This includes both open jack pine forest with little ground cover (few or no shrubs, blueberry plants, lichen,

etc.) and closed forests with dense shrub and forb in understorey. Most jack pines in the Key Lake area are from 85 to 150 years old, and forest productivity and species diversity are lower than other areas in the Athabasca basin. Vegetation in low lands with organic soil, and poor drainage is typically dominated by open black spruce forest with an understorey of shrub and moss. Tamarack and swamp birch are also present in lowland areas, but are less common. Other predominant vegetative cover in wetlands are wet sedge meadow and rush-sedge cotton grass meadow.

4.0 Research Program for Flat Areas (1976-1995)

Immediately after exploration a research program was started which lasted until 1986. The program resulted in a hydroseeding program with criteria for the type, quantity and rate of materials to be applied. The research program was expanded in 1993 to include the climax species, i.e., the jackpine trees. The program culminated in a complete and successful reclamation program for all flat areas at Key Lake. The following subsections briefly describe these research programs.

4.1 (1976-1986) Research Program

Due to unforgiving environmental conditions, the invasion of trees and shrubs to a disturbed area is a very slow process. As a result, numerous studies were performed from 1978 to 1986 to identify the most effective:

- agronomic and native species;
- site preparation method;
- seeding methods and rates;
- fertilizer application methods, rates, timing and frequency;
- irrigation rates and methods;
- tree planting and maintenance procedures;
- soil amendments (lake sediments, lime, mulches, tackifiers, peat, hydrophillic agents); and
- transition from agronomic to self-sustaining vegetative cover.

Based on these research activities the following conclusions were made:

- The most successful species were: boreal red fescue, sheep's fescue, Carlton smooth brome, annual ryegrass and Fairway crested wheatgrass.
- None of the legumes tested survived past the first year.
- The native plants indicated low survival rates. In addition, they were found too costly and therefore, not recommended for large scale reforestation programs.
- Containerized jack pine, if not fed upon by animals, survived well and is preferable to bare roots.
- Seeds that are not covered by soil, hardly ever germinate and are easily blown away or eaten by birds. The seed could be harrowed, raked or covered by mulch. Seed application rates of 100 kg/ha was found to be the most effective.
- Hydroseeding, despite its disadvantages, was found to be the most suitable and economic method for large scale revegetation application.
- The soil analysis indicated that the soil media is deficient in all major nutrients. An initial application of 100 kg/ha for each of N, P_20_5 and K_20 followed by an annual application of 100 kg/ha of N and P_20_5 was proven to be very successful. Also, the timing of the application is very important (Courtney, 1987).

4.2 1993-1995 Research Program

1993-94 Research Program

The new research programs had two components - laboratory and field programs. The laboratory program was composed of identifying species that grow naturally in the Key Lake area (both the pioneering and climax species) and collecting seeds, samples or specimens from them and propagating the species in the nursery and transplanting them in the field under various conditions. The key was to find the native species that could adapt themselves from ideal conditions in the nursery to the harsh conditions at the site.

The field program was composed of planting the actual native plants grown under laboratory conditions and the most prevalent species (e.g. jack pine seedlings) and study the major factors affecting their growth and performance under various conditions. These factors may include, but not limited to:

- genetics of the species to be planted;
- soil quality, slope and aspect of the area;
- exposure to wind and the associated abrasion;
- ongoing erosion of the area; and,
- moisture regime.

The focus of 1993 experimental season, was making a comparison between hydroseeded and non-hydroseeded areas of the mine site. This was to examine the potential competition between the grasses and the jack pine seedlings. The study sites were selected and the seedlings planted. The treatments used were; Control, Peat Slurry Dip, Alcasorb Root Dip, Wood Chip Protection, Shingle Protection, Desert Tamer and Tire Protection.

The experimental design for 1993 consisted of a single treatment for each plot. The design of the plots was somewhat different in 1994, with each plot composed of 5-6 rows, with each row receiving a different treatment. This change was made to avoid bias to any treatment, due to differences in soil quality, exposure or moisture regime at a given site.

Fertilizer stakes used in 1993 were omitted from the 1994 study, as they were noted to "burn out" the seedlings and enhance competitive grass growth around the trees that did survive. The other amendment that was deleted from the 1994 study, was shingles placed on the south side of the seedlings. Although this was meant to shade the area to slow down moisture loss, the trees were noted to be growing to the side, apparently attempting to get into direct sunlight.

1995 Research Program

In order to address the utilization of native vegetation species for reclamation at Key Lake, several species were collected (i.e. plants and cuttings) from northern Saskatchewan and propagated in the greenhouse. These species include:

Grasses
Calamagrostis neglecta - narrow reed grass
Carex foenea - hay sedge
Bromus pumpellianus - northern awnless brome
Festuca rubra - red fescue
Calamagrostis inexpensis - northern reed grass
Agrostis scabra - rough hair grass

Woody Species
Vaccinium sp. - blueberry
Salix sp. - willow
Populus balsamifera - balsam poplar
Populus tremuloides - trembling *aspen*

Chamaedaphne calyculata - leatherleaf
Betula sp. - birch
Prunus pennsylvanica - pincherry
Pinus banksiana - jack pine

Three sites were chosen that represented the environmental conditions at the Key Lake. At each site an experimental plot design with 16 plots representing 4 replicates of each of the following treatments, was set up:

T1 - Control with no wind fence and no hydromulch and fertilization
T2 - Wind protection (snowfence) with no hydromulch
T3 - Wind protection (snowfence) with hydromulch
T4 - No wind protection (exposed) with hydromulch

The grass plugs were planted in the perimeter of each plot. Also 70 jack pine seedlings (7 rows of ten seedlings each) were planted on each plot. The experimental sites are; Site 3-Moderately harsh environment, Site 17 - Mild environment and Site 21 - Extremely harsh environment (a south-facing slope of the waste rock pile with modified slopes of a 3.5:1).

Additional Experimental Seedling Plots 1995

Site 4 -Mill Hill area directly between the mill and the mine shop. Four 10m x 10m plots were established; two on the crest of the hill and two on the side-slope facing the mine shop. At each location, a control plot and a plot treated with approximately 6.25 kg of lime were set up. At each plot, 100 jack pine seedlings, were planted.

Site 21 - Treatments that were tried at this location include slope modification and seedling protection. These plots were located west of the grass experimental plots and consisted of the following:

Small shallow pits (shelter pits), approximately 20 cm wide and 10 cm deep were dug, with the soil from the hole placed on the north side of the seedling. The intent of this treatment was to create a small wind protection mound for the seedling, while creating a depression to hold moisture. The seedling was planted half way up the created slope to be protected by the mound, but not flooded.

A portion of the side-slope of Site 21 was delineated into four-100 metre sections. Two sections were altered by walking a bulldozer perpendicular to the slope to create a series of ridges on the slope-face. The intent was to create a more protective, stable environment for the seedlings to become established, particularly during the first year. The ridges decrease the erosive force of the wind, protect the seedlings from the abrasive blowing sands, aid in moisture retention and erosion caused by runoff. The other two sections were left untreated, with respect to terrain alteration.

Half of the Control and the Ridged areas were covered with mulch to determine the effects of the added erosion control. All four areas were then planted with jack pine seedlings. Due to uneven ridges, the number of seedlings in each area were not identical.

Site E-This site is located immediately north of the Gaertner Pit and is exposed, with little surrounding cover. Due to the exposure plants in this area are subjected to "sand blasting". In addition, seeds are blown away from the area prohibiting seed germination. In Site E several treatments were established in an attempt to protect the seedlings from the wind and blowing sand. The treatments were: pits, control, shingles, alcosorb and windfence (Johannessen et al, 1995).

Windfence - An area of approximately 12m x 12m was surrounded by a commercially available plastic windfence. The windfence was porous and was used to provide a wind break, thereby decreasing the wind speed and minimizing the abrasive effects of the sand. The fence may also enhance moisture retention of the soil by decreasing evaporative potential of the wind. This will allow the seedlings to better establish themselves.

Grass Seed Mixture Trials

At Sites 3, 17 and 21 grass seed mixture trials were conducted to determine the success of commercially available cultivars, including: Durar hard fescue, Streambank wheatgrass, slender wheatgrass, Canada blue grass, northern wheatgrass, and creeping red fescue. The areas were fertilized at a rate of approximately 27.5 kg/ha of nitrogen and 5.7 kg/ha of potassium. The seeding rate was approximately 1.5 kg/ha, with the seeds broadcast seeded and lightly raked. Each plot was 2m x 2m. At each of the three sites, one series of plots was covered with hydromulch, and the others used as a Control.

Seedling Development Experimental Area

This plot was established in Site C (existing site 25) for the measurement of root and stem development of the seedlings planted in 1995. Every 4-6 weeks, 10 seedlings were collected and the length and dry weight of the stem and roots of the seedling were measured. This allowed the researchers to evaluate the development of the seedlings and to determine the shoot : root weight ratio of the seedlings. The frequency of this program was reduced to once a year in 1996 and 1997. This monitoring program is not performed any more.

The measurements were taken from collar to shoot tip and collar to root tip. The samples were cleaned of their rooting medium and dried for 48 hours at 50° C. Care was taken not to remove fine rootlets. After the samples were dried, their weights were determined with a Mettler electronic balance at the Key Lake chemistry laboratory.

In addition, the shoot height and stem thickness of two hundred seedlings have been measured since 1995 to gauge the growth of the seedlings.

5.0 Research Program for Slope Areas (1998-Present)

5.1 Experiment I - Slope Revegetation

The specific objectives of Experiment I were to:

- identify the soil characteristics of the various sloped areas;
- replicate and test various treatment options on different slopes; and,
- test the "patch theory" on the slopes and flat areas of the site.

During a preliminary survey of the various slopes at site, four slope types were identified; unplantable rock slopes, plantable rock slopes, clay slopes and sandy slopes.

Unplantable Rock Slopes

At present, it appears appropriate to leave the stable, unplantable rock slopes as they are. The rocks are continually weathering and breaking down to small particles. In addition, the deciduous trees establishing themselves would enhance the weathering process. As rocks weather, and the resulting fines erode, the fines will form gentler slopes, creating a safer medium for planters to walk on.

Plantable Rock Slopes

Two (2) replicates of two different density plantings were tested on the top and bottom slopes, on a north-facing and a south-facing slope, for a total of 16 plots. The plots were approximately 2 m x 2 m in size and spaced approximately 5 m apart.

The low density plots received 2 jackpine seedlings, 1 willow or balsam poplar cutting, 1 birch cutting, 1 fireweed, 2 F. rubra plugs and 2 Deschampsia caespitosa plugs. The high density plots received 4 jackpine seedlings, 3 willow or

balsam poplar cuttings, 3 birch cuttings, 6 fireweed, 8 F. rubra plugs and 8 Deschampsia caespitosa plugs. Each plot was marked with a lath in the centre of the plot for proper identification.

In these plots, the efficiency of the low versus high-density stocking to achieve coverage of the plot, and/or expansion into adjacent areas is being tested. For this reason, plants that are known to be prolific seed producers were planted. This would eventually prove the validity of planting small patches throughout the site and allow them to expand into the adjacent areas, rather than trying to revegetate the whole rocky area.

Clay Slopes

To test the potential of the grasses to expand on the soil medium of the clay areas of the waste rock piles, two (2) replicates of two (2) treatments on the upper and lower slopes on both a north-facing and south-facing slope (clay portion of Site 21 immediately south of the Deilmann Pit) were established. This corresponds to 16 plots in total.

The treatments, in 4 m x 4 m plots, were as follows:
Treatment 1 (Patch Theory) -

Each plot contains 3 rows of 15 grass plugs (C. neglecta, B. pumpellianus, and F. rubra), followed by five rows of jackpine seedlings (15 seedlings per plot), two rows of grass plugs at the bottom (D. caespetosa, C. inexpansa), and finally 3 birch and three willow or balsam poplar cuttings randomly placed among the jackpine. These plots were labeled as Plugs.

Treatment 2 -

The plot was hydroseeded with a mixture that contains commercially available boreal red fescue and 10grams of the native seed harvested from Key Lake. In addition, each plot received 15 jackpine seedlings per plot. These plots were labeled as HYDRO.

Sandy Slopes

The same treatments described for the clay slopes were applied to steep sandy slopes, that could safely be worked on, such as those on portions of Site 21. Again, south-facing and north-facing slopes in excess of 3:1 were tested, resulting in 16 plots on each slope. This should provide information on the maximum slope that could be revegetated without slope modification.

Note: All of the experimental plots were fertilized at a rate of 200 kg/ha.

5.2 Experiment II - Native Seed Investigation

Seed Viability/Germination Test

The objective of this program was to explore the possibility of directly applying jack pine and other native seeds into a disturbed area and document the results. Prior to field tests, greenhouse trials were performed under laboratory conditions. Germination and emergence of the selected seed types were tested under ideal growth conditions to provide baseline data for comparison with the field results for the same species.

To facilitate these experiments, four buckets of sand and clay were collected at Key Lake and sent to the greenhouse. Seeds harvested in the previous summer from the grass in the farms at Hourglass Lake and Site 17 were planted in trays containing either sand or clay, as well as on filter paper in petri dishes with water. Two hundred (200) seeds of each type of grass were used for each trial and repeated twice.

The coated (treatment coated and ash coated) and uncoated jackpine seeds were also germinated in the greenhouse in Key lake media to establish baseline. The same procedures described in the previous paragraph for the grass seed germination trials were followed.

Direct Seeding of Jackpine Seed and Native Grass Seed

The following design, planted on Site 21 was used to test the effectiveness and efficiency of a single application of native grass seeds and jackpine seeds harvested from the Key Lake ecoregion. This was examined using a split-plot design. A total of three blocks (replicates) were used. The five treatments were:

Treatment 1 (control) - native seed mixture + harrow + hydromulch
Treatment 2 - native seed mixture + harrow
Treatment 3 - native seed mixture + hydromulch
Treatment 4 - native seed mixture
Treatment 5 - commercial seed mixture + native seed + harrow + hydromulch

Three treatments of jackpine seeds were used randomly throughout the plots, and are described below:

1 - uncoated stratified seed (S1) – red

2 - coated, stratified seed - ash type (S2) - green

3 - coated, stratified seed - regular type (S3) - orange

The color-coding refers to the corresponding spray paint on the stakes marking the plots.

Prior to planting, the site was harrowed and staked out into three blocks of five 4m x 4m plots with 5m between plots in each block and between blocks. Each plot was labeled with `meanstreak' permanent marker and spray painted. Using a hand held spreader, each plot received 10 grams of the above seed mixture (equivalent to 60 kg/ha). After each plot was seeded, four rows with each containing fifty jackpine seeds were manually applied to the plots.

Three additional plots were added to the east side of the area and labeled S1T6, T7 and S1T8, with the treatments described below:

S1T6 - native seed mix + harrow + hydromulch + uncoated jackpine seed + 15 jackpine seedlings

T7 - native seed mix + harrow + hydromulch + 15 jackpine seedlings

S1T8 - native seed mix + harrow + uncoated jackpine seed + 3 birch seedlings + 3 willow cuttings

Finally, a border designed to provide shelter for the plots was established. The border consists of commercial seed that was planted and harrowed, and four rows of willows, birch and balsam poplar. All plots and borders were fertilized at a rate of 200kg/ha.

5.3 Permanent Monitoring Plots

Thirty six (36) permanent monitoring plots were established within representative revegetation sites throughout Key Lake. The plots were located to ensure complete representation of all site types (e.g., exposed versus protected areas; sandy soil versus clay soil). Further, the plots were sited to monitor the natural encroachment pattern of vegetation from undisturbed forest along the edges of the disturbed sites, and the revegetation pattern at the centre of the revegetation site. The permanent plots were established at 5m x 4m and marked with metal posts extending 1.5 m above the ground ensuring permanent markings of the plots.

6.0 Five-Year Revegetation Plan

The Five-year Revegetation Plan evolved out of twenty years of experimental reclamation projects (1976-1996) completed on site. The plan serves as a basis for the continuation of the regreening process of disturbed areas at Key Lake, and will be used in conjunction with ongoing experimental plots to determine the best overall reclamation approach. Thirty six sites were identified that require reclamation. The sites are described in detail, with reference to previous disturbance, existing vegetation (natural and experimental), soil texture, aspects and pH. The following briefly outline the major features of the five-year plan:

- All sites requiring revegetation that may be available over the following five years are identified at any time;
- The natural features, i.e. soil texture, slope, aspects, pH and types of natural and introduced species are identified in detail for each site;
- The best method of revegetating each site is discussed in detail and accordingly a tentative schedule has been set up;
- The plan will be used as a guide to track the success/failure of various methods that are being used at each site;
- The plan is flexible to allow new and proven methods to be incorporated in upcoming five-year plan; and
- The plan encourages the use of native and non-invasive species that are more adaptable to the climate and other environmental conditions at Key Lake.

7.0 Assessment Methodology

The methodologies used for various vegetation assessments completed at Cameco Key Lake operation, in 1998, are described in the following subsections. The 1998 measurements were taken in August and October.

7.1 Research Plot Assessments (Grass/Shrub/Jackpine)

7.1.1 Grass Growth Vigor Assessment Measurements

Measurements taken from the grasses on Sites 3, 17 and 21 were designed to provide information on vegetative growth extent and patterns, as well as the production of fruiting bodies (*i.e.*, seed heads), and are as follows:

dominant height -measured from the base of the plant to the dominant height (maximum height the majority of the grass shoots extend to). Portions of the grasses may extend higher than the dominant height;

base width - base width of the grass clump where the majority of the tillers are initiating from;

aerial extent - extent of cover afforded by the grasses for the surrounding soils;

tillers - the number of new growth tillers established during that growing season. The values were grouped into: Class 1 (1-25 new tillers); Class 2 (26-50 new tillers); and Class 3 (>50 new tillers); and,

fruiting bodies - the number of fruiting bodies (seed heads) produced by the plant during that growing season. The values were grouped into: Class 1 (1-25 seed heads); Class 2 (26-50 seed heads); and Class 3 (>50 seed heads).

Five plants were selected at random and the above measurements taken for data analysis.

7.1.2 Jackpine Seedling Assessment Measurements

To gather qualitative information on jackpine seedlings on research plots at Sites 3, 17, 21 and 34; the following measurements were taken:

shoot height - measured from the top of the collar to the tip of the apical meristem;

caliper width - width of the shoot, measured with a Vernier caliper, approximately 1 cm above the collar; and,

seedling vigor - a subjective assessment on the vitality of the seedling based on the ratio of live to dead needles. For example, Class 1 (all needles green, healthy); Class 2 (>50% green); Class 3 (<50% green); and Class 4 (shoot is dead).

Ten seedlings were selected at random from the seventy seedlings per plot, and the above measurements taken for the assessment. All measurements are in Centimetre.

7.2 Visual Assessment of Jackpine Seedling Vigor

The methodology for the 1998 visual assessment of the experimental plot jackpine seedlings planted in 1993-1995 and the grass plugs planted in 1995 have been carried each since 1994. The Ratings varied from 0 (dead) to 4 (excellent vigor) for the seedlings and a qualitative description of the grasses.

8. Results

8.1 Research Plot Assessments (Grass/Shrub/Jackpine)

8.1.1 Grass and Sedge Assessment

Tables 8.1.1 to 8.1.3 presents the survival rates for the perimeter grasses planted at Sites 3, 17 and 21 respectively. Although the survival rates vary from site to site the general trend for most species, is toward a reduction in height, increase in base width and an increase in vegetative reproduction. Seed production is abundant for most species. Nutrient availability continues to be the main growth limiting factor at all sites, as evidenced by Table 8.1.4 comparing fertilized to unfertilized treatments.

The plot treatment types at each site are as follows:

T1 - control - no wind fence, no fertilizer, no hydromulch

T2 - wind fence only (removed in autumn 1996)

T3 - wind fence (removed in autumn 1996), fertilizer and hydromulch

T4 - no wind fence, fertilizer and hydromulch

On Sites 3 and 17, only plots labeled T3 and T4 have been fertilized at 200 kg/ha each spring, while all plots at Site 21 have been fertilized yearly at 200 kg/ha.

The assessment of the grass/sedge/shrub/tree experimental plots, established at Sites 3, 17 and 21, show the importance of nutrient availability. Grasses on all plots are generally showing a trend toward vegetative reproduction and seed production, with a decrease in overall height. Plants of all species growing on the plots located at the middle and bottom of Site 21 show better growth than those located at the top of the slope. Survival rates for the perimeter grasses on these sites were as follows: Site 3 (range 82 - 96%); Site 17 (65 - 96%); and Site 21 (45 - 95%) Table 8.1.1, 8.1.2 and 8.1.3 respectively.

The plots that are not receiving fertilizer are showing a trend towards degeneration of the aboveground biomass and health. The plants on Site 3 are showing the least growth, indicating that this site is the harshest of the three. Some of the plant species (*e.g.*, fireweed, northern wheatgrass, *Agrostis scabra*) on Sites 17 and 21 are showing an affinity for spreading throughout the site. The largest cause of mortality on Site 21, is water erosion.

Table 8.1.1
Survival Rates for the Perimeter Plot Grasses
at Site 3

Species	% Survival 1995	% Survival 1996	% Survival 1997	% Survival 1998	1995-1998 Mean (%)
Calamagrostis neglecta	98	94	96	96	96
Carex foenea	96	94	84	88	90.5
Festuca rubra	93	93	94	87	91.75
Bromus pumpellianus	90	86	87	82	86.25
Mean	94.75	91.75	90.25	88.28	91.13

Table 8.1.2
Survival Rates for the Perimeter Plot Grasses
at Site 17

Species	% Survival 1995	% Survival 1996	% Survival 1997	% Survival 1998	1995-1998 Mean (%)
Calamagrostis neglecta	89	85	72	65	77.75
Festuca rubra	96	99	99	94	97.00
Bromus pumpellianus	96	93	92	92	93.25
Carex foenea	94	97	95	86	93.00
Deschampsia caespitosa	100	99	84	96	94.75
Mean	95.00	94.60	88.40	86.60	91.15

Table 8.1.3
Survival Rates for the Perimeter Plot Grasses
at Site 21

Species	% Survival 1995	% Survival 1996	% Survival 1997	% Survival 1998	1995-1998 Mean (%)
Calamagrostis neglecta	98	94	86.3	84	90.58
Carex foenea	88	80	66	45	69.75
Deschampsia caespatosa	98	97	88.5	82	91.38
Bromus pumpellianus	96	89	83	95	90.75
Festuca rubra	97	95	94	95	95.25
Mean	95.40	91.00	83.56	80.20	87.54

Table 8.1.4
Percentage Survival Comparison between Fertilized and Unfertilized Plots at Sites 3 and 17
Key Lake, 1998

Species	Site 3		Site 17	
	Unfertilized	Fertilized	Unfertilized	Fertilized
Species	T1 & T2 % Survival	T3 & T4 % Survival	T1 & T2 % Survival	T3 & T4 % Survival
Calamagrostis neglecta	100	96	42	79
Carex foenea	84	92	71	99
Festuca rubra	96	94	81	97
Bromus pumpellianus	72	91	64	94
Mean	88.00	93.25	64.50	92.25

8.1.2 Experimental Plot Jackpine and Deciduous Tree Assessment

In addition to the grasses and sedges, the woody species (willow, birch, balsam poplar, jackpine, pincherry and blueberry planted in the experimental plots at Sites 3, 17 and 21 were also evaluated. The survival of jackpine seedlings is shown below in Table 8.1.5.

Table 8.1.5
Jackpine Survival Rates for the Experimental Plots
Key Lake, 1998

Jackpine Survival Rate (%)				
Treatment	Site 3	Site 17	Site 21	Mean
T1	93.6	99.6	58.5	83.90
T2	87.1	98.9	75.4	87.13
T3	92.1	96.8	81.8	90.23
T4	85.4	100	72.1	85.83
Mean	89.55	98.83	71.95	86.78

8.1.3 Jackpine Seedling Vigor Assessment

Micronutrient Experimental Plots

The four treatment plots and one control plot were compared against each other, and between the 1997 and 1998 sampling years to detect any trends (Table 8.1.6). Jackpine seedlings on micronutrient plots showed increases of 24-89% in mean height, and 33-83% for mean caliper width. At least some of this gain could be attributed to general fertilizing of the entire site that was completed in 1997 and 1998.

Table 8.1.6
Mean Jackpine Seedling Height and Caliper Width for the Different Micronutrient Plots at Site 34

Site 34 Micronutrient							
Plot Designation	Mean Height (cm)			Mean Caliper Width (cm)			Comments
	1997	1998	% Increase	1997	1998	% Increase	
NE	23.2	28.77	24.00	0.75	1.00	33.33	Yellow needles noted.
NW	20.1	33.93	68.81	0.70	1.07	52.86	Yellow needles noted.
SE	18.0	27.94	55.22	0.61	1.05	72.13	Good growth.
SW	17.6	33.25	88.92	0.64	1.17	82.81	Good growth.
Control	18.4	28.61	55.49	0.63	0.94	49.21	Fair growth.

NE: Granular Fertilizer, 40 ml micronutrient in 20 litres of water
NW: 0 Granular Fertilizer, 40 ml micronutrient in 20 litres of water
SE: Granular Fertilizer, 20 ml micronutrient in 20 litres of water
SW: 0 Granular Fertilizer, 20 ml micronutrient in 20 litres of water
Control: 0 Granular Fertilizer; 0 ml micronutrient

Macronutrient Experimental Plots

The macronutrient experiment included manually broadcast fertilizer and containerized macronutrient/slow release fertilizer trials at Site 34. The mean values for caliper diameter and shoot height for the different macronutrient plots are presented, and compared to the 1997 findings, in Table 8.1.7. The percentage increase in shoot height for the jackpine seedlings in the macronutrient trials ranged from 55% to 110%. The trials with the highest increases were the nutricote (110%), Scot high (109%) and Scot low (95%). The control, and two manually fertilized plots, showed increases of 55% and 56% respectively.

Table 8.1.7
Mean Jackpine Seedling Height and Width for the Different Macronutrient/Slow Release Plots at Site 34

Site 34 Macronutrient Trials							
Plot Designation	Mean Height (cm)			Mean Caliper Width (cm)			Comments
	1997	1998	% Increase	1997	1998	% Increase	
Control	18.4	28.61	55.49	0.63	0.94	49.21	Fair growth.
Fertilizer East	20.4	32.15	57.59	0.54	0.91	68.52	Fair growth.
Fertilizer West	20.2	31.55	56.18	0.56	0.97	73.21	Good growth.
Nutricote	19.3	40.68	110.78	0.53	1.23	132.08	Excellent growth.
Scot Low	20.1	39.21	95.07	0.58	1.15	98.28	Good growth.
Scot High	19.5	40.89	109.69	0.58	1.15	98.28	Good growth.

The percentage increases measured for the stem caliper widths showed similar trends with the nutricote trials showing the highest increase (132%), and the control seedlings exhibiting the lowest increase (49%). Again, the containerized fertilizer trials showed higher gains than the control and manually fertilized plots.

8.2 1998 Experiments

8.2.1 Experiment I - Slope Revegetation

A one-in-one-hundred-year storm event occurred at Key Lake in July, shortly after the new test plots were established. As a result, the majority of 1998 slope revegetation plots were severely damaged.

All plots were surveyed in September, 1998. Clay slopes were rated as sustaining more damage than the sand slopes. Water eroded away the clay and formed deep rills in the face of the slope, causing the removal of most of the plants. The sandy slopes also lost some vegetation, however, it appears that the sand was able to dissipate much of the energy from the rain, thereby resulting in less erosion. Plants which remained on the sandy slopes appeared to be healthier than the ones on the clay slopes.

To assess these plots, the number of remaining plants were counted and their vigor noted. Also, the percent cover of planted grass (Hydro plots only) was recorded and the number of stems per square metre counted. This proved difficult for most of the Hydro plots as the water erosion had removed most of the planted seed.

8.2.2 Experiment II

8.2.2.1 Seed Viability/Germination Test

Native Grass Seeds

The germination tests completed under laboratory conditions varied with species and with the growth media used. For example, in clay, germination ranged from a low of 3% for *Calamagrostis inexspansa* to a high of 60% for *C. neglecta*. In sand, germination ranged from 38% for *Bromus pumpellianus* to 69% for *C. inexspansa*. In the petri dish, germination ranged from 14% for C. neglecta to 86% for *Festuca rubra*.

8.3 Visual Assessment of Jackpine Seedling Vigor

Overall, the seedlings planted in the 1993-1995 experimental plots showed little to no decline in survival rates over the past year. The year of planting and the rate change from 1997 to 1998 are as follows: 1993 (decrease from 79.0% to 78.6%); 1994 (no change); 1995 (decrease from 86.6% to 82.7%); and 1996 (Site 34 fertilizer treatment plots decrease from 100% to 98%).

8.4 Seedling Micronutrient Tests

Jackpine seedlings on micronutrient plots showed increases of 24-89% in mean height, and 33-83% for mean caliper width. At least some of this gain could be attributed to general fertilizing of the entire site that was completed in 1997 and 1998.

8.5 Seedling Macronutrient Tests

Macronutrient trials showed increases in mean shoot height per treatment over the past year as being: Nutricote (110%); Scot high (109%); Scot low (95%); manually fertilized (56%); and control (55%). Caliper diameter increases showed the same trends with Nutricote showing the highest increase of 132% and the control seedlings showing the lowest increase of 49%.

8.6 Landscape Assessment of Revegetation Sites

Each of revegetation sites identified in the 5-year management plan was assessed with respect to landscape criteria. The assessment parameters include; Drainage, Erosion, Contour, Stability, Gravel and Rocks, Debris, Vegetation, Bare Areas, Soil and Contamination.

8.7 Permanent Monitoring Plots

The Daubenmire technique (Daubenmire 1959) was used to estimate percentage cover of a permanent monitoring plot. A Daubenmire plot frame (20 cm x 50 cm) was placed in each of the north-west and south-east corners of each of the permanent plots, and the vegetation, detritus and bare ground percentage cover estimated for each of the subsamples. This system utilizes a class system to represent a range of cover by a given species of vegetation or other cover type (*e.g.*, bare ground). The class and percentage cover range are: Class 1 (0-5%); Class 2 (5-25%); Class 3 (25-50%); Class 4 (50-75%); Class 5 (75-95%); and Class 6 (95-100%). The results will be used as a baseline to monitor the health, growth of vegetation and the natural encroachment onto the plots. A detailed presentation of the findings is beyond the scope of this paper.

9.0 Observations/Recommendations

Based on the data presented thus far the following conclusions/observation could be made:

a) Soil stabilization prior to seed germination and or tree planting is a significant factor in establishment of vegetation in any disturbed area.

b) Damages due to wind erosion could severely impede the growth of all species regardless of types. The air borne sand particles are extremely abrasive and sandblast the plants.

c) Due to lack of nutrient in the soil, the plants require nutrient supplements for the first few years before they can become self-sufficient. Th timing and type of the fertilizer are also important factors to be considered.

d) Native species of plants from the Key Lake ecoregion, perform better than standard commercial seed mixtures. The jackpine seedlings, grown from cones collected at the mine site appear to have a better initial vigor than seedlings grown from stock from other ecoregions. The native grass species collected from the Athabasca Sand Dunes, as part of the research component of the project, have performed better than southern grassland/parkland pasture grass mixtures. The native willow, birch and balsam poplar cuttings that were planted are also showing early signs of healthy establishment.

e) Planting jackpine seedlings on bare, exposed sand areas is not practical. Jackpine seedlings appear to need stabilized, semi-sheltered conditions to grow and develop properly. The seedlings are prone to physical damage from blowing sand, and dehydration due to exposure if planted in an unprotected, open area.

f) Although snow fencing is capable of providing good protection for plants during their early establishment phases, it will damage the seedlings and grasses if not maintained.

g) Jackpine seedlings exhibit better growth under conditions where they are protected from being sand blasted.

h) Seed drilling followed by hydromulch application appears to be a good method to achieve the following: accurate seed placement; better seed to soil contact; protection of the seeds; moisture conservation; and erosion control. This would conserve seed and lower input costs. Hydroseeding may cause significant seed mortality and is susceptible to water and wind erosion, particularly if applied sparsely.

i) Mature (>50 years old) stands of jackpine forest in the vicinity of Key Lake have a tree density of 600-1300 trees/ha. And based on the survival rates achieved thus far, it appears a density of approximately 2000 trees/ha is a practical approach.

j) Natural encroachment of native species (*e.g.*, willow, fire weed, blueberry) is occurring to different degrees on all of the sites that have been stabilized. This encroachment is more noticeable on the smaller sites, and around the periphery of the larger sites.

k) Some of the native grass species being experimented with are showing good potential for vegetative expansion (*i.e.*, reproduction through rhizomes) over the growing season. *Calamagrostis neglecta* shows the best expansion potential will be useful for stabilizing steep, sandy slopes. The other grass species exhibit more clumped growth and more seed production.

l) There appears to be several different site conditions within the Key Lake mine site which will require slight adjustments to the revegetation program. Soil textures, slopes, stoniness, aspect, moisture availability and surrounding vegetation are all important factors that contribute to the reclamation protocol required to successfully revegetate the area.

m) To reduce the risk of slope wash out by severe storms, a watershed plan should be developed for waste rock piles and other areas with slopes prior to revegetation.

n) Since different materials behave differently during a severe storm, considerations should also be given to the type of materials

(clay vs sand) on slope areas for revegetation.

10.0 LITERATURE CITED

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